Proceedings of ROADS AND TRAFFIC SAFETY ON TWO CONTINENTS in Gothenburg, Sweden, 9-11 September 1987

- Speed
- Vehicle Performance
- Crashworthiness
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PREFACE

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

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

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

In the sessions of roads, the emphasis on the Strategic Highway Research Program (SHRP) was intended. Presentations did highlight differences between European and US practices and needs, and the discussions was concentrated on how to promote international involvement in SHRP and application of its research.

Linköping January 1988

Kenneth Asp

Proceedings of ROADS AND TRAFFIC SAFETY ON TWO CONTINENTS in Gothenburg, Sweden, 9-11 September 1987:

VTI RAPPORT 328 A
- Opening
- Traffic Safety - Open Session
- Traffic Safety - General

VTI RAPPORT 329 A
- Long Term Pavement Performance
- Asphalt

VTI RAPPORT 330 A
- Highway Operations
- Concrete and Structures

VTI RAPPORT 331 A
- Driver Behaviour and Licensing
- Alcohol and Drugs
- Driving and Elderly

VTI RAPPORT 332 A
- Speed
- Vehicle Performance
- Crashworthiness
SPEED

SPEED LIMIT ENFORCEMENT IN THE UNITED STATES:
THE PROBLEM OF RADAR DETECTORS
Mr Brian O'Neill, Senior Vice President, and Mr Mike Ciccone,
The Insurance Institute Highway Safety (IIHS), USA

THE EFFECTS OF POLICE SURVEILLANCE STRATEGIES AND PUBLICITY CAMPAIGNS ON SPEEDING BEHAVIOUR
Dr Talib Rothengatter, Traffic Research Centre, University of Groningen, The Netherlands

IMPLICATIONS OF RAISING THE U S MAXIMUM SPEED LIMIT TO 65 MPH
Mr Stephen R Godwin, Senior Program Officer, Transportation Research Board, USA

THE SPEED LIMIT EXPERIMENTS ON PUBLIC ROADS IN FINLAND
Dr Markku Salusjärvi, Technical Research Centre of Finland

SPEED LIMITS AND ACCIDENT CONSEQUENCES AND RISKS
Dr Göran Nilsson, VTI, Sweden

SPEED LIMIT IN RURAL AREAS IN DENMARK 1973-1986
Mr Hans W Lund, civil engineer, Traffic Safety Research Board, Denmark

LA GESTION DE LA LIMITATION DE LA VITESSE: PROBLÈMES ET PERSPECTIVES
(Speed Limits. Problems and Perspectives)
Directeur Yvon Chich, Institut National de Recherche sur les Transports et leur Sécurité (INRETS), France

VTI RAPPORT 332 A
VEHICLE PERFORMANCE

SOCIAL, ECONOMIC AND INSTITUTIONAL IMPEDIMENTS TO THE HARMONIZATION OF VEHICLE SAFETY STANDARDS
Mr Christopher Wilson, Director, Department of Transport, Canada

USING COMPUTER GRAPHICS TO COMPARE US AND EUROPEAN BEAM PATTERNS
Mr Eugene Farber, Ford Motor Co., USA

COMPUTER CONTROLLED SUSPENSION (CCS)
Lars Runo Tillback, Volvo Car Corp, Sweden

A TIRE MODEL FOR ALL SIMULATED CAR-DRIVER SITUATIONS
Prof Dr Techn Friedrich Böhm, Technische Universität, Berlin, The Federal Republic of Germany

ANTI-LOCK BRAKING SYSTEM PERFORMANCE. INTERNATIONAL REGULATIONS NOW AND IN THE FUTURE - SOME SWEDISH VIEWPOINTS.
Dr Olle Nordström, VTI, Sweden

PERIODIC VEHICLE INSPECTION IN SWEDEN - EXPERIENCES AND VIEWPOINTS
Dr Gösta E Svensson, AB Svensk Bilprovning, Sweden

CRASHWORTHINESS

COLLISIONS INVOLVING PASSENGER CARS WITH DRIVER SIDE AIR BAGS
Mr David J. Romeo; President, Romeo Engineering International, Inc, USA,
Mr Leif Svensson; President, Hedemora Car Technique Ltd, Sweden
Prof Jan Thorsson, The Foundation for Health and Safety for State Employees in Sweden
CHILD RESTRAINTS IN EUROPE
Mr Thomas Turbell, Research Director, VTI, Sweden

THE CHILD IN THE VOLVO CAR
Gerd Carlsson and Jan Holmgren, Hans Norin, Volvo Car Corp, Sweden

SIDE COLLISIONS AND CRASHWORTHINESS
Prof B Friedel, Bundesanstalt für Strassenwesen (BAST), The Federal Republic of Germany
ABSTRACT

The papers presented at the seminar were as follows: Speed Limit Enforcement in the United States. The problem of Radar Detectors (O'Neill, B); The Effects of Police Surveillance Strategies and Publicity Campaigns on Speeding Behaviour (Rothengatter, T); Implications of Raising the US Maximum Speed Limit to 65 mph (Godwin, S); The Speed Limit Experiments on Public Roads in Finland (Salusjaervi, M); Speed Limits and Accident Consequences and Risks (Nilsson, G); Speed Limit in Rural Areas in Denmark 1973-1986 (Lund, H); Speed Limits. Problems and Perspectives (Chich, Y); Social, Economic and Institutional Impediments to the Harmonization of Vehicle Safety Standards (Wilson, C); Using Computer Graphics to compare US and European Beam Patterns (Farber, E); Computer Controlled Suspension (CCS) (Tillback, L R); A Tire Model for all Simulated Car-Driver Situations (Boehm, F); Anti-Lock Braking System Performance. International Regulations now and in the future. Some Swedish Viewpoints (Nordstroem, O); Periodic Vehicle Inspection in Sweden. Experiences and Viewpoints (Svensson, G E); Collisions involving Passenger Cars with Driver Side Air Bags (Romeo, D J, Svensson, L and Thorsson, J); Child Restraints in Europe (Turbell, T); The Child Safety in Cars (Carlsson, G, Holmgren, J and Norin, H); Side Collisions and Crashworthiness (Friedel, B).
**WEDNESDAY SEPTEMBER 9**

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<td>Mr David Phillips, Associate Administrator, R &amp; D Technology, Federal Highway Administration, USA</td>
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<td>Road Safety Research in the Federal Republic of Germany</td>
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<td>Dr A Hitchcock, Head of Safety and Transportation Group, Transport and Road Research Laboratory (TRRL), U.K.</td>
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<td>Discussion on how to improve the cooperation between Europe and the United States within the field of traffic safety research.</td>
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THURSDAY SEPTEMBER 10

ASPHALT
8.30—12.00
Chairman: Mr Francis Francois, Executive dir of AASHTO, USA

Asphalt Characteristics Portion of SHRP
Dr A D Andreas, Dep secretary of Transportation, Washington DOT, USA

Asphalt Characteristics Portion of SHRP
Mr A D Andreas, Dep secretary of Transportation, Washington DOT, USA

French research on the methods of characterisation of asphalt, polymer modified binders, asphalt mixes
Dr J Bonnot, Laboratoire central des ponts et chaussées, France

Bituminous Binders — Nordic Overview
Dr Olav E Ruud, Norway

Dynamic Testing of Recycled Asphalt
Prof Dr G Paulmann, Technische Hochschule Darmstadt, the Federal Republic of Germany

Mix Design in the United Kingdom
Dr Richard Salters, University of Birmingham, United Kingdom

Panel discussion

ALCOHOL AND DRUGS
8.30—12.00
Chairman: Dir General George Dobias, INRETS, France

Effects of Minimum Drinking Age on Fatalities in the United States
Mr Paul Hoxie, Transportation Systems Center, USA

License Removal at Time of Arrest for Driving While Intoxicated: An Approach with Promise in the US
Mr John H Lacee, Program manager — Alcohol Studies, Univ of North Carolina, USA

Drinking and Driving: Institutional and Social Aspects of Law Enforcement
Dr Jayet Marie Chantal, Institut National de Recherche sur les transports et leur sécurité (INRETS), France

The Drinking and Driving Problem in Norway
Dr Alf Glad, Institute of Transport Economics, Etterstad, Oslo

Enforcement of Drunk-Driving Laws by use of “Per Se” Legal Alcohol Limits: Blood and/or Breath Concentration as the Definition of Impairment
Dr Wayne Jones, Department of Alcohol Toxicology, National Laboratory of Forensic Chemistry, Sweden

Driver Improvement and Rehabilitation of DWIs: The Influence of American Approaches on the Establishment of Treatment Programs in Central Europe.
Dr Edgar Spoerer, Inst for Education, Perfec-

Discussion

12.00 LUNCH

HIGHSWAY OPERATIONS
13.30—17.00
Chairman: Dr L-E Bergfalk, National Road Administration, Sweden

Highway Operations Portion of SHRP
Mr A D Andreas, Dep secretary of Transportation, Washington DOT, USA

Highway Operations Portion of SHRP
Mr David Minsk, Research Physical Scientist, US Army, CRREL, USA

Evaluation of the surface treatment techniques in France (chip seal and other very thin surfacings)
Dr J Bonnot, Laboratoire central des ponts et chaussées, France

Development of maintenance management and control Systems
Dr L-E Bergfalk, National Road Administration, Sweden

Highway Snow and Ice Control — Nordic Overview
Dr Kent Gustafsson, VTI, Sweden

Panel discussion

DRIVING AND THE ELDERLY
13.30—17.00
Chairman: Dir K B. Johns, Transportation Research Board, USA

Experiences in Fatalities by Age and Road User Groups — USA vs Western Europe 1970—1983
Prof Rudolger Lamm, Clarkson University, USA

Elderly Drivers in Europe
Prof Kåre Rumar, VTI, Sweden

Driving and the Elderly
Mr Stephen R Godwin, Senior Program officer, Transportation Research Board, USA

Elderly drivers and traffic safety in France
Dr G Dobias/Dr M Muhlried, INRETS, France

Driving and the Elderly
Prof Dr Günter Kroj, Bundesanstalt für Straßenwesen (BAST), the Federal Republic of Germany

Discussion

VEHICLE PERFORMANCE
13.30—17.00
Chairman: Prof Dr H Praxenthaler, Head of the Road and Traffic Research Laboratory (BAST), the Federal Republic of Germany

Social, Economic and Institutional Impediments to the Harmonization of Vehicle Safety Standards
Dir Christopher Wilson, Department of Transport, Canada

Headlamp Performance Evaluation Techniques
Mr Eugene Farber, Principal Staff Engineer, Ford Motor Co, USA

Computer Controlled Suspension (CCS)
Lars Runo Tillback, Volvo Car Corp, Sweden

A Tiremodel for All Simulated Car-Driver Situations
Prof Dr Techn F Böhm, Technische Universität, Berlin, the Federal Republic of Germany

Anti-lock Braking Systems in USA vs Europe
Dr Dilo Nordström, VTI, Sweden

Periodic Vehicle Inspection in Sweden — Experiences and View Points
Dr Sven Asander, Svensk Bilprovning AB, Sweden

Discussion
### FRIDAY SEPTEMBER 11

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| **Chairman:** Dir Ivar Schacke, Head of the Danish Road Research Laboratory, Denmark  
Concrete and Structure Portion of SHRP  
Mr Howard Newlon, Research Director, Virginia Highway & Transportation Research Council, USA  
Development in the Netherlands in the field of concrete and structures and concrete block paving  
Dr Van der Vring, The Netherlands  
Durability of Road and Bridge Structures of Concrete Nordic experiences  
Dr Bo Göran Hellers, Head of Swedish Cement and Concrete Research Institute, Sweden  
Norwegian Practice for Concrete Bridge Deck Protection  
Dr Erling K Hansen and Dr John E Haga, Norwegian Road Research Laboratory  
The use of 2 metre square Precast Concrete Rafts as Temporary, Reusable and Cost-Effective Roads  
Dr John W Bull, University of Newcastle upon Tyne, United Kingdom  
Panel discussion | **Chairman:** Dr Brian O’Neill, senior vice president, The Insurance Institute Highway Safety (IIHS), USA  
Speed Limit Enforcement in the United States: The problem of Radar Detection  
Dr Brian O’Neill, IIHS, USA  
The Effects of Police Surveillance Strategies Publicity Campaigns on Speeding Behaviour  
Dr Talib Rothengatter, Traffic Research Centre, Univ of Groningen, The Netherlands  
Implications of Raising the US 55 MPH Maximum Speed Limit  
Mr Stephen R Godwin, Senior Program Officer, TRB, USA  
The Speed Limit Experiments on Public Roads in Finland  
Dr Markku Salousjärvi, Technical Research Centre of Finland  
Speed Limits and Accident Consequences and Risks  
Dr Göran Nilsson, VTI, Sweden  
Speed Limit in Rural Areas in Denmark 1973—1986  
Dr Hans W Lund, Traffic Safety Research Board, Denmark  
Discussion | **Chairman:** Professor Bertil Aldman, Chalmers technology, Sweden  
Collisions Involving Passenger Cars with Driver Side Air Bags. A US-Swedish R & D-Project  
Jan Thorsson, The Foundation for Health and Safety for State Employees in Sweden  
Child Restraints in Europe  
Thomas Turbell, VTI, Sweden  
The Child Safety in Cars  
Gerd Carlsson, Volvo Car Corp, Sweden  
Side Collisions and Crashworthiness  
Prof Bernd Friedel, Bundesanstalt für Strassenwesen (BAST), the Federal Republic of Germany  
A Systems Approach for Harmonization of Standards  
Prof Bertil Aldman, Chalmers, Sweden  
Discussion |

**12.00 LUNCH AND CLOSING REMARKS**
SPEED LIMIT ENFORCEMENT IN THE U.S.: THE PROBLEM OF RADAR DETECTORS

by Brian O'Neill, senior vice president and Mike Ciccone, The Insurance Institute Highway Safety (IIHS), USA

In most of the United States, the principal tool for enforcing speed limits is police radar. The U.S. Federal Communications Commission (FCC) has given police agencies the authority to operate radars at only two specified frequencies. The use of only these two frequencies has led to the development of devices called radar detectors that receive transmitted signals with these frequencies and sound a warning when a signal is detected. The idea behind these devices is that they warn drivers early enough so that they can slow down before police radar units can measure their speed. Some of the radar detectors on the market today can warn of the presence of police radar at considerable distances. Inexplicably, only two states and the District of Columbia prohibit the use of such devices despite the fact that they serve no purpose other than to aid motorists in violating speed limits.

Data collected in two states on vehicle travel speeds using measurement procedures that could not be identified by the radar detectors show that when hidden police radar units were suddenly activated, over 10 percent of speeding vehicles abruptly slowed down. The faster a vehicle was travelling, the more likely it was to slow down. When police radar units were operated continuously, average speeds dropped and the proportion of vehicles travelling substantially over the speed limits declined dramatically. This research provided clear evidence that radar detectors are being widely used to elude police speed enforcement and that travel speeds on the U.S. highways are faster than they would be in the absence of radar detectors.
Speed Limit Enforcement in the United States:  
The Problem of Radar Detectors

Brian O'Neill  
Michael A. Ciccone

August 1987

Insurance Institute for Highway Safety  
Watergate 600  
Washington, D.C. 20037

This work was supported by the  
Insurance Institute for Highway Safety

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ACKNOWLEDGEMENT

The following individuals and organizations are gratefully acknowledged for their invaluable support in planning, executing, and reporting this study: Center for Applied Research, Inc.; Mark Goodson of Goodson Engineering, Inc.; Jessica Pollner of Longbranch Research Associates, Inc.; Jeffrey Wentz of the Maryland Department of Transportation; Lt. Raymond Cotton and Lt. Frank Rayne of the Maryland State Police; National Technical Systems; Jerome Hall of the University of New Mexico; Lynwood Butner, John Hannah, and A.L. Thomas of the Virginia Department of Highways and Transportation; Capt. Basil Belsches and Lt. Col. Charles Robinson of the Virginia Department of State Police; and Adrian Lund, Sharon Rasmussen, Howard Stein, JoAnn Wells, and Jackson Wong of the Insurance Institute for Highway Safety.
INTRODUCTION

In the United States (U.S.) speed limits are set by the individual states, although since 1974 the federal government has in effect established maximum speed limits by threatening to withhold federal highway construction funds from any state that has a speed limit higher than a maximum established by the federal government. Until early this year the national maximum speed limit was 89 kilometers per hour (km/h); now states are permitted to establish speed limits as high as 105 km/h on rural interstate highways only, but the maximum limit on all other roads remains at 89 km/h.

In the U.S., as in several European countries, many drivers — a majority on some roads — routinely exceed speed limits. Although official speed limits are frequently exceeded, they do make a difference because they, in effect, set unofficial upper limits that only a few motorists will exceed. The unofficial upper limit is about 16 km/h higher than the official limit. In recent years, however, the proportion of U.S. drivers exceeding the maximum speed limit has been increasing. For example, the U.S. Federal Highway Administration estimates that the average proportion of drivers traveling faster than 16 km/h above the speed limit on rural interstate highways has increased from about 9 percent in 1981 to 18 percent in 1986 (U.S. DOT, 1982;1987).
It has been argued that this increasing willingness by many motorists to substantially exceed the official maximum speed limit was due to the 89 km/h limit being too low. Now that many states are increasing their maximum speed limits to 105 km/h, this theory can be tested. Another factor in growing noncompliance with the speed limits is likely to be the increasing availability of relatively low cost radar detectors, which are used to alert speeding drivers to the presence of police officers enforcing speed limits with radar units.

In most of the U.S., the principal tool for enforcing speed limits is police radar. The U.S. Federal Communications Commission, which regulates radio and microwave transmissions, has given police agencies authority to operate speed measuring radar units at two specified frequencies. This has led to the development of radar detectors, which are devices designed to receive the transmitted signals from police radar and warn drivers when such signals are detected. The idea behind these devices is that they warn drivers early enough so that they can slow down before the police radar units can measure their speeds.

In the state of Maryland between July 1985 and May 1986, about one-third of the passenger vehicles stopped for speeding after being identified by a nonradar method of speed measurement were found to be equipped with radar detectors. And among the commercial vehicles cited for speeding, almost 80 Percent had radar detectors (Maryland State Police, 1986).
Despite the fact that the only purpose for radar detectors is to help motorists violate speed limits, they are legal in all U.S. jurisdictions except Virginia, Connecticut, and the District of Columbia. The current study measures the influence of radar detectors on speed behavior in the state of Virginia, which prohibits radar detectors, and the adjacent state of Maryland, which does not. In addition, speed measurements taken in New Mexico, the first state to raise the speed limit from 89 to 105 km/h on rural interstate highways, are presented.

**METHODS**

Three sets of data were collected in Maryland: speed distributions in the presence and absence of conventional police radar as measured by an automatic speed monitoring station; speed distributions in the presence or absence of police radar measured by special radar units using frequencies not receivable by radar detectors; and speed changes among speeding vehicles as measured by the special nondetectable radar units when hidden police radar was suddenly activated. Data collection procedures were similar in Virginia except that speed distributions from monitoring stations were not collected. In New Mexico, only speed distributions in the absence of police radar as measured by nondetectable radar were collected. All data were gathered during clear or overcast weather with dry pavement on mostly level, straight roadways on
interstate and primary highways with speed limits of 89 or 105 km/h. Speed measurements were obtained in freely moving traffic.

**Speed Distributions from a Monitoring Station**

Vehicle speeds and lengths were measured using inductance loops, which are wires embedded in the pavement and connected to electronic recorders at the roadside. The monitoring station was located on a rural four-lane interstate highway in Maryland with a posted speed limit of 89 km/h. A standard police radar was activated during alternating hours while the monitoring station was automatically recording traffic data. The radar unit, which was used solely as a transmitter of signals capable of activating radar detectors, was placed adjacent to the electronic recorders at the roadside and was switched on or off at the start of each hour. Data included hourly vehicle counts according to length, as well as numbers and proportions of vehicles exceeding 105 and 121 km/h during each one-hour interval.

**Speed Distributions from Radar**

In this part of the study, speed data were collected using the special nondetectable radar unit. With this nondetectable radar, speeds of vehicles in free-flowing traffic were measured at four sites each in Maryland and Virginia and two sites in New Mexico. The Maryland and Virginia sites had
posted speed limits of 89 km/h; the New Mexico sites had limits that had recently been increased from 89 to 105 km/h. A standard police (detectable) radar unit was also used in Maryland and Virginia for half of the total observation time; its function was to serve solely as a transmitter of radar signals capable of activating radar detectors.

The transmitting antennas of the radar units were kept out of view inside a parked observation vehicle. The antenna of the nondetectable radar was aimed at either approaching or receding traffic, and when used, the antenna of the detectable radar was always aimed at approaching traffic.

Observed vehicles were classified into five main types in Maryland and Virginia: passenger cars, sports/specialty cars, light trucks, straight trucks, and tractor-trailer trucks. Sports/specialty cars were defined according to Highway Loss Data Institute (1986) criteria as two-seaters, convertibles, midsize and larger cars with two or fewer designated rear seating positions, and luxury vehicles. Passenger cars were defined as cars other than sports/specialty cars. Light trucks were defined as all pickups, vans, and utility vehicles (gross vehicle weights typically under 4500 kg). Straight trucks were defined as all single-unit trucks with gross vehicle weights generally over 4500 kg (e.g., step vans, dump trucks); buses were included with straight trucks. Tractor-trailer trucks were defined as combination trucks with one or more trailers; bobtails (tractor units without trailers) were included with
tractor-trailers. In New Mexico, the categories were the same, except no distinction was made between passenger cars and sports/specialty cars.

Speed Changes in Response to Activated Detectable Radar

Nondetectable radar was aimed at approaching traffic and left on continuously at seven paired locations in Maryland and Virginia. All sites had posted speed limits of 89 km/h. When an unobstructed vehicle traveling at an initial speed of 99 km/h or more was observed, the detectable radar unit, which was also aimed toward approaching traffic, was activated for 15 to 30 seconds and any change in vehicle speed indicated by the nondetectable radar unit was recorded.

A speed change was defined as the initial observed speed minus the speed after the detectable radar was activated. Among vehicles traveling at least 10 km/h above the speed limit, a speed change of at least 8 km/h when the detectable radar was suddenly activated was taken as an indication of the use of a radar detector. A slowdown of at least 8 km/h was chosen because this reduction was judged large enough to reflect an intentional reduction in travel speed in response to the radar signal rather than a change due to other reasons. At least 30 seconds elapsed after each observation before the detectable radar was turned on for the next target vehicle. This waiting period minimized the possibility that the subsequent vehicle would have detected the radar signal.
intended for the previous vehicle. The observed vehicles were also classified according to type, as described in the preceding section.

RESULTS

Table 1 shows the percentages of vehicles exceeding the speed limit by more than 16 and 32 km/h as measured by a monitoring station. The results are shown separately for the periods when the hidden police radar was operating and when it was inactive. During the 11 hours when data were collected with the police radar not operating, 25 percent of the cars and light trucks and 27 percent of the tractor-trailers were exceeding the speed limit by more than 16 km/h. When the police radar unit was operating, these percentages dropped to 21 percent and 11 percent, respectively. Among the smaller number of vehicles traveling even faster — more than 32 km/h above the speed limit — the percentage reductions during the periods when the police radar unit was operating were even greater (Table 1).

Table 2 shows the percentages of vehicles exceeding the speed limit by more than 16 and 23 km/h in Maryland and Virginia as measured by the special nondetectable radar unit. The speed distributions summarized in Table 2 were obtained at a variety of locations in each of the states, and it is clear that the percentages of vehicles exceeding the speed limits by more than 16 km/h are considerably lower than those shown in
Table 1, which are from the single monitoring station location. In both Maryland and Virginia, the percentages of vehicles exceeding the speed limits by more than 16 and 23 km/h showed significant declines when the hidden police radar units were activated.

Figure 1 shows the percentages of speeding vehicles slowing down at least 8 km/h when detectable police radar was suddenly activated. Overall about 11 percent of the speeding vehicles slowed down suddenly when the police radar unit was activated, but this percentage varied significantly by vehicle type and by initial travel speed. Among passenger cars initially measured at speeds between 17 and 23 km/h above the speed limit, about 10 percent slowed down suddenly. Among the passenger cars traveling even faster -- those exceeding the speed limit by more than 23 km/h -- over 20 percent slowed down suddenly. In the case of tractor-trailers, the corresponding percentages were 44 and 50 percent, respectively. These results strongly suggest that about 20 percent of the fastest traveling passenger cars and 50 percent of the drivers of the fastest traveling tractor-trailers were using radar detectors.

Table 3 shows the percentages of vehicles in New Mexico exceeding the new 105 km/h speed limit the first week after it was raised, and 9 and 17 weeks later. All of the speeds were measured by the special nondetectable radar unit. One week after the speed limit was increased, about 5 percent of the passenger cars and 7 percent of the tractor-trailers were
exceeding the speed limit by more than 7 km/h and less than 1 percent of the vehicles were exceeding the speed limit by more than 16 km/h. Nine weeks later the percentages exceeding the speed limit by more than 7 km/h had increased to 12 and 11 percent, respectively. The percentage of passenger cars exceeding the speed limit by more than 16 km/h increased only slightly, but the percentage of tractor-trailers increased sharply. The results at 17 weeks after the speed limit change are very similar to those for 9 weeks after, suggesting that for the time being, travel speeds may have somewhat stabilized.

DISCUSSION

This study has shown that many motorists in the U.S. routinely exceed the posted speed limits and that in the absence of police radar the proportion of vehicles traveling at higher speeds is greater. The changes in speeding behavior when hidden police radar units were operating compared to when they were not were more pronounced for tractor-trailers than for other vehicle types. The results strongly suggest that radar detectors are being widely used by drivers of speeding vehicles to elude police enforcement of speed limits and that travel speeds on U.S. highways are faster than they would be without radar detectors.

The results from two adjacent states -- Virginia, which prohibits the use of radar detectors, and Maryland, which does not -- suggest that the effect of Virginia's prohibition is
limited. This is perhaps not surprising given the amount of interstate travel and the ease with which radar detectors can be purchased. Early models of radar detectors were typically placed on the car dashboard and were visible to enforcement officers. Virginia State Police have issued substantial numbers of citations to motorists for violating the prohibition on radar detectors in that state. Newer models of radar detectors, however, are much smaller and easier to conceal making it much more difficult for the police to identify offenders. Extensive advertising in national magazines suggests that the use of radar detectors is likely to continue to grow until more states prohibit their use and techniques are developed to identify vehicles with radar detectors in use.

A number of organizations and groups have recognized the problems created by the use of radar detectors and have begun to urge more states to prohibit their sale and use (Uniform Motor Vehicle Code, 1987; Hricko and Fields, 1987; Allstate Ins. Co., 1987). To date, however, such efforts have not been able to overcome the efforts of the radar detector manufacturers to prevent such legislation. The Governor of Michigan indicated that he would not support higher speed limits without a corresponding prohibition on the sale and use of radar detectors, but the state legislature did not incorporate this prohibition in the legislation raising the speed limit. As a result the Governor vetoed the higher speed limit. If European countries use the same frequencies as the
U.S. for police radar units, it seems likely that radar
detectors will begin to proliferate in Europe. The time to
implement legislation prohibiting this product, which serves no
purpose other than to break the law, is before they are in
widespread use and before radar detector manufacturers become
an economic force.

Many people have argued that many motorists in the U.S.
ave chosen to routinely exceed speed limits and use radar
detectors to avoid police speed enforcement because the old
aximum speed limit of 89 km/h was too low. Higher speed
imits are now permitted and in the first state with the higher
peed limit (105 km/h), the most recent traffic speed
asurements suggest that, although many motorists are
ceeding the new limit, relatively few are exceeding it by
re than 16 km/h. There is no reason to believe, however,
at higher speed limits will lead to any significant decrease
the use of radar detectors. Although many motorists use the
official speed limit to set their own higher personal limit,
there will always be some drivers who believe that getting from
one place to another as fast as possible is much more important
than any increased crash risk. Unfortunately, the availability
of radar detectors provides such drivers with an opportunity to
reduce their chances of being caught by the police while
speeding


<table>
<thead>
<tr>
<th>Vehicles</th>
<th>Police Radar Unit Operating</th>
<th>Percentage Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Cars and Light Trucks</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of vehicles measured</td>
<td>5,212</td>
<td>5,237</td>
</tr>
<tr>
<td>Percentage exceeding speed limit by more than 16 km/h</td>
<td>25</td>
<td>21</td>
</tr>
<tr>
<td>Percentage exceeding speed limit by more than 32 km/h</td>
<td>2.8</td>
<td>1.6</td>
</tr>
<tr>
<td><strong>Tractor-Trailers</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of vehicles measured</td>
<td>567</td>
<td>570</td>
</tr>
<tr>
<td>Percentage exceeding speed limit by more than 16 km/h</td>
<td>27</td>
<td>11</td>
</tr>
<tr>
<td>Percentage exceeding speed limit by more than 32 km/h</td>
<td>0.7</td>
<td>0.2</td>
</tr>
</tbody>
</table>
Table 2

The Influence of Police Radar Units on the Percentages of Vehicles in Maryland and Virginia Exceeding the Speed Limit (89 km/h)--
All Speeds Measured by Nondetectable Radar

<table>
<thead>
<tr>
<th>Police Radar Unit Operating</th>
<th>Number of Vehicles Measured</th>
<th>Percentage Exceeding Speed Limit by More than 16 km/h</th>
<th>Percentage Exceeding Speed Limit by More than 23 km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No</td>
<td>Yes</td>
<td>Change</td>
</tr>
<tr>
<td>Number of vehicles measured</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maryland</td>
<td>1,600</td>
<td>1,711</td>
<td></td>
</tr>
<tr>
<td>Virginia</td>
<td>1,235</td>
<td>1,316</td>
<td></td>
</tr>
<tr>
<td>Percentage exceeding speed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>limit by more than 16 km/h</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maryland</td>
<td>5.8</td>
<td>3.7</td>
<td>-36</td>
</tr>
<tr>
<td>Virginia</td>
<td>7.0</td>
<td>5.4</td>
<td>-23</td>
</tr>
<tr>
<td>Percentage exceeding speed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>limit by more than 23 km/h</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maryland</td>
<td>1.3</td>
<td>0.8</td>
<td>-38</td>
</tr>
<tr>
<td>Virginia</td>
<td>1.2</td>
<td>0.6</td>
<td>-50</td>
</tr>
</tbody>
</table>
Table 3

Percentages of Vehicles in New Mexico Exceeding New Speed Limit (105 km/h) One, Nine, and Seventeen Weeks After it was Increased—All Speeds Measured by Nondetectable Radar

<table>
<thead>
<tr>
<th>Vehicles</th>
<th>Period After Speed Limit Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 Week</td>
</tr>
<tr>
<td>Passenger Cars</td>
<td></td>
</tr>
<tr>
<td>Number of vehicles measured</td>
<td>766</td>
</tr>
<tr>
<td>Percentage exceeding speed limit by more than:</td>
<td></td>
</tr>
<tr>
<td>7 km/h</td>
<td>5</td>
</tr>
<tr>
<td>16 km/h</td>
<td>0.8</td>
</tr>
<tr>
<td>Tractor-Trailers</td>
<td></td>
</tr>
<tr>
<td>Number of vehicles measured</td>
<td>445</td>
</tr>
<tr>
<td>Percentage exceeding speed limit by more than:</td>
<td></td>
</tr>
<tr>
<td>7 km/h</td>
<td>7</td>
</tr>
<tr>
<td>16 km/h</td>
<td>0.2</td>
</tr>
</tbody>
</table>
Figure 1

Percentage of Vehicles Slowing at least 8 km/h
In the Presence of Suddenly Activated Detectable Radar

Initial Speed:
- 106-112 km/h
- >112 km/h

Percent

0 10 20 30 40 50 60

Passenger Cars  Sports/ Specialty Cars  Light Trucks  Straight Trucks  Tractor-Trailer Trucks
The effects of police surveillance strategies and publicity campaigns on speeding behaviour

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Abstract
Speeding behaviour on undivided inter urban roads is considered to be a major road safety problem. On average about 75% of the drivers exceed the legal limit of 80 kmh. A number of experiments have been carried out to investigate the effects of publicity campaigns, different police surveillance strategies and the influence of variation in the intensity of speed limit enforcement on speed limit compliance and on the attitudes of drivers towards speeding. Speed choice was measured through continuous speed registration and individual radar measurements on control and experimental roads. Attitudes and opinions were measured with questionnaires which were send to drivers who regularly used the roads under study. Large differences were found in the effectiveness of different surveillance strategies. The publicity campaigns were found to have a large, but transitory effect on speed choice. Combination of publicity and police enforcement produced more lasting effects, than either activity alone. Although small changes were found in the perceptions of the road users who were subjected to the police and publicity activities, no lasting attitude changes could be demonstrated.

The results of these experiments are discussed both in theoretical terms and in terms of practical implications for police surveillance activities.
IMPLICATIONS OF RAISING THE U.S. MAXIMUM SPEED LIMIT TO 65 MPH

Stephen R. Godwin
Senior Program Officer
Transportation Research Board

ABSTRACT

As is the case with many controversial policy decisions, the recent decision of the U.S. Congress to allow the states to increase maximum speed limits to 65 mph involves conflicts in both technical issues and value preferences. This paper briefly reviews the transition in maximum speed limit policy setting from a traffic engineering-based decision made at the state level to a highly politicized decision made at the national level. The effect of posted speed limits on motorist behavior and their subsequent safety benefits are among the most debated technical issues regarding maximum speed limits; this paper highlights these issues by reviewing the experience of the United States with the 55 mph speed limit. This same experience is drawn on to project the benefits and costs of allowing states to raise speeds to 65 mph. The paper also describes three alternate approaches to establishing speed limits: reliance on the 85th percentile of prevailing speeds, use of benefit-cost analysis to define an optimum speed limit, and the current "incremental" approach. The paper compares the ability of these three alternate approaches to explicitly treat disagreements in society regarding the relative importance of safety compared to travel time, and concludes with recommendations for evaluation research.
IMPLICATIONS OF RAISING THE U.S. MAXIMUM SPEED LIMIT TO 65 MPH

Stephen R. Godwin
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The energy crisis of 1973, which helped produce the 55 mph maximum speed limit, changed the way speed limits are determined in the United States. Even the recent vote by the U.S. Congress to allow states to increase speed limits to 65 mph occurred within the precedents set by the 55 mph maximum limit. Rather than being a judgment based on a traffic engineering rule-of-thumb, the maximum limit has become a political judgment balancing safety, travel time, personal freedom and states' rights. This paper summarizes how speed limit policy has evolved to the current stage in the U.S. and reviews alternate approaches to establishing maximum speed limits.

HISTORY OF SPEED LIMIT POLICY IN THE U.S.

Earliest Approaches

Public officials in the U.S. have wrestled with reasonable speed limit policies since well before the energy crisis of 1973. Indeed, the first speed regulations predate the invention of the automobile by over 200 years. The town of Newport, Rhode Island attempted to prevent the deaths of pedestrians by prohibiting the galloping of horses on major thoroughfares, and Boston, Massachusetts limited horsedrawn carriages to a "foot pace" on Sundays to protect churchgoers (Ladd 1959). In 1901,

1The opinions expressed in this paper are those of the author and not necessarily those of the Transportation Research Board or the National Research Council.
shortly after the advent of automobiles, the State of Connecticut set the first maximum speed limit in the U.S. at a maximum speed limit of 8 mph (Labatut 1950). These policies were typical of the earliest approaches to speed limits. Local officials posted maximum limits to protect pedestrians rather than to benefit vehicular traffic flow.

These early policy precedents were shattered by the enormous growth in automobile travel in the early part of the 20th century. By 1930, millions of motorists were driving cars capable of traveling 80 to 100 mph when the maximum speed limit posted in most rural areas was about 40 mph (Joscelyn and Elston 1970). At this time some 23 million motor vehicles were in operation in the U.S. (Federal Highway Administration 1978). The demands of motorists for higher speeds could scarcely be denied, despite a fatality rate of about 15.6 deaths per 100 million vehicle miles travelled (MVMT) in 1930 (roughly 6 times higher than the national average for 1985) (National Safety Council 1985).

Aside from a temporary imposition of a federal 35 mph speed limit during World War II, state and local governments determined speed limit policy. Traffic engineers, however, appeared to share the opinion that speed limits were ineffective. According to a University of Illinois study done in 1948, motorists drove at speeds they believed reasonable, regardless of the posted speed, and most maximum limits were considered below those deemed reasonable by motorists (The American City 1950).
Advent of 85th Percentile Method

During the 1950s traffic engineers began advocating an approach to speed limits that accommodated the preferred driving speeds of the public. Spot speed surveys of free flowing traffic provided an approximation of the distribution of speeds, and the limit was established where 85 percent of motorists were in compliance (Johnstone 1956). Early support for the 85th percentile method was driven by an attempt to keep up with motorist speeds, but advocates of this method also argued that the setting the speed limit between the 80th and 90th percentile slowed down the fastest drivers and caused the slowest drivers to speed up, thereby reducing the variability of speed on the highway and contributing to safer driving (Matson et al. 1955). Despite the lack of any scientific verification for this theory at the time (some supporting research was conducted later), the 85th percentile method became the most popular method for setting speed limits, and by 1970 was by far the most frequently used method by cities and states around the country (Joscelyn and Elston 1970).

Advent of Nationally Determined Maximum Speed Limits

The 55 mph National Maximum Speed Limit was established by Congress during the energy crisis of 1973. During this period, public support for any policy to reduce reliance on imported oil was high; consequently, motorists slowed down on almost all highway systems. On rural Interstate highways, the highest quality system in the U.S., average speeds declined from 65 mph to 57.6 mph between 1973 and 1974 (Figure 1) (TRB 1984). In addition, the variability in speeds -- the difference between the slowest
and fastest drivers -- narrowed considerably. The standard deviation, a measure of speed variability, declined from 8.5 mph to 6.4 mph (Figure 2). This reduced variability came as something of a surprise because the 85th percentile method had been justified partly on the basis that it narrowed the variability in speeds. Yet here was a policy -- chosen for its fuel saving potential -- that resulted in an even narrower speed variability.

Although the 55 mph maximum limit was meant to conserve fuel, because of slower and more uniform speeds, highway safety improved dramatically in 1974. Due to the many effects of the energy crisis and because of the 55 mph speed limit, the fatality rate per 100 MVMT declined 16 percent. On high speed highways, the decline was even greater. The fatality rate on rural Interstates declined by 34 percent (Figure 3). Nationwide, 9,100 fewer traffic deaths occurred in 1974. Because of this remarkable reduction in fatalities -- the largest annual decline since WWII -- Congress made the temporary energy policy a permanent safety policy.

In a recent retrospective evaluation of the 55 mph speed limit, TRB estimated that the 55 mph limit was responsible for about 3,000 to 5,000 of the 9,100 fewer traffic deaths that occurred in 1974, and estimated that it continued to save 2,000 to 4,000 lives in more recent years (TRB 1984). The TRB report reviewed dozens of studies evaluating the effect of the 55 mph speed limit and compared international experience with speed limits. That report and and other recent articles detail the analysis underlying the safety benefits of the 55 mph limit (TRB 1984, Deen and Godwin 1985; Godwin and Kulash 1987). This paper merely summarizes those results and uses them to project the consequences of the 65 mph limit.
The TRB report also noted that whereas compliance with the 55 mph speed limit was eroding slightly each year, the 55 mph limit had a continued effect on average speeds. Average speeds on rural Interstates, for example, were still but 59.6 mph in 1986, still about 5 mph slower than in 1973 (Figure 1). Perhaps equally important, the standard deviation in speeds remained at about 6 mph. Although average speeds remained slower, motorist dissatisfaction with the law grew, and a higher percentage violated the limit with each passing year.

For over a decade, public opinion polls showed that support for the 55 mph speed limit remained fairly constant; over 70 percent of those polled voiced support for the law. This voiced support for the law did not translate into literal compliance. Nearly two-thirds of drivers who said they supported the 55 mph limit admitted to driving 5 mph or so over the limit, but also believed that they were complying with the law (TRB 1984). Motorists recognize that the police tolerate small violations and have come to expect this enforcement "tolerance." Thus the safety benefits of speed limits must be viewed based on their effect on aggregate speed behavior and not on the extent to which they command literal compliance with the posted limit. Since 1985, however, while a slightly greater percentage of motorists violated the limit, a remarkable decline in public support occurred. By 1986 aggregate support had slipped to just 50 percent (AAA 1987). California, a state with 10 percent of total drivers, had already reported a majority of California residents respondents opposed to the law (California Highway Patrol 1985). This drop in support in national surveys occurred as the 55 mph speed limit was
being debated in Congress, and roughly corresponds with a statement by the President that the maximum limit was a policy that should be handled at the state rather than at the federal level.

The national highway legislation, which reauthorizes federal funding for the national highway program every four years, was caught up in the debate over maximum speed limits, and failed to pass the 99th Congress, partially because the House of Representatives and the Senate disagreed on whether the 55 mph speed limit should be retained. Some Senators, mostly from the western states, argued that the policy was inappropriate for the sparsely populated western states, and that it cost over a billion hours of travel time each year (Congressional Record 1986). The Senate passed a bill allowing the states to increase speed limits to 65 mph on rural Interstate highways only. Opponents of higher speed limits in the House argued that repeal of the 55 mph speed limit on rural Interstates would cost 500 lives each year.

Although the Senate version of the speed limit bill finally passed in the 100th Congress, many features of the 55 mph policy remain. Most notably, the decision about the maximum limit appropriate for all highways and states is made at the national level rather than being set for individual highway segments based on a traffic engineering-based method such as the 85th percentile of prevailing speeds. The key difference in this new policy is that the federal government will no longer require the states to monitor traffic speeds on the rural Interstates as an indicator of how well they are enforcing the limit.
The requirement that the states monitor speeds on 55 mph posted highways and keep half of the traffic in compliance with the law, or be subject to a loss of up to 10 percent of their federal highway aid, had become one of the most politically unpopular aspects of the policy. In 1986, the federal government found that three states failed to meet the standard. Although the financial penalties were fairly small, the mere withholding of funds—the symbolic heavy hand of the national government—was resented at the state level. Despite state resistance to the federal presence in this policy area, however, the new 65 mph speed limit falls far short of a return to a policy of allowing the states to set speed limits.

IMPLICATIONS OF HIGHER SPEED LIMITS

Effects on Safety

The potential effect of higher speeds on safety was at the center of the Congressional debate about higher speeds. Whether safety would be diminished was never seriously at issue. The research on the effects of lowering the speed limit to 55 mph in the U.S. only disagreed about the size of the safety benefit (TRB 1984). Research abroad, notably the work of Nilsson, has made the case that higher speed limits increase casualties and that lower speed limits reduce them (Nilsson 1982). But in the debate over the 55 mph speed limit, a central question was not whether safety would be affected, but the number of lives that might be lost due to higher speeds.
The 1984 TRB report estimated that a return to the speed conditions that prevailed on rural Interstates in 1973 would result in an additional 500 fatalities. The technique for estimating this effect is relatively straightforward. Between 1973 and 1974 fatalities on rural Interstates fell by 34 percent and roughly a third to a half of the decline in fatalities can be attributed to the slower and more uniform speeds caused by the 55 mph speed limit (TRB 1984). Assuming that the speed limit was repealed, and other things held constant, one could expect fatalities to increase by 10 to almost 20 percent (34% x 0.33 or 0.55).

Other things, of course, have not held constant over this period. Three major influences on safety have to be accounted for: (1) erosion in motorist compliance; (2) other improvements to vehicles and roadways, and (3) the increased travel on the highway system that increases the number of motorists at risk.

*Speed Effects*

Average speeds have crept up somewhat since 1974, from 57.6 to 59.6 mph, thus roughly 70 percent of the average speed decline remains despite eroding compliance. At the same time, however, the variability in speeds has remained constant. Since the benefits of the 55 mph speed limit might depend solely on the variability in speeds, one could argue that 100 percent of the speed benefit has been retained. This seems unlikely because higher speed crashes are necessarily more severe. Thus the speed effect is probably not as much as 100 percent of what it was in 1974 and probably no less than 70 percent of what is was. For simplicity, I use the midpoint between these two percentages and assume that the speed effect is 85 percent of what it once was on rural Interstates.
Other Safety Improvements

Many gains have been made in vehicles and roadways. Most notably, improvements made to vehicle crashworthiness appear to have contributed to the declining fatality rate (Graham and Garber 1985). Other safety gains result from improvements such as new crash attenuators that have been designed and placed around many bridge abutments and improved guardrail designs that more safely deflect errant vehicles. Although it is impossible to accurately estimate the individual effects of these improvements, they are all a part of the gradual decline in fatality rates experienced on rural Interstates. The fatality rate on rural Interstates has declined 26 percent since 1974. Although these improvements are clearly interactive, both with themselves and with speed, nonetheless it is possible to approximate the extent to which other safety gains offset the consequences of higher speed by assuming that the decline in the fatality rate provides an index of how much the 1974 speed effect has been offset by other safety gains. In this instance one could argue that since fatality rates have declined by about 26 percent, this would offset the effects of any increase in speeds.

Travel Effects

Since total travel on the rural Interstate has increased from 119 million vehicle miles in 1974 to 158 hundred million vehicle miles, an increase in speed limits would increase the severity of crashes for many more occupants than in 1974. Thus the 1974 speed effect would have to be increased 33 percent to account for the growth in travel.
A rough estimate of the effect of higher speeds can be calculated by assuming the 1974 speed effect on rural interstates is 85 percent of what it was, that it would be reduced by the effect of other improvements to safety (multiplying by 0.736) and then increased by a factor of 1.33 to account for the increased number of motorists at risk. These calculations suggest that roughly 500 additional fatalities would occur in 1988 if speeds return to an average speed of 65 mph on rural Interstates in all states. The only other recent quantitative estimate in the technical literature of the consequences of higher speeds on rural Interstates, which uses a completely different set of assumptions and calculations, also arrives at an estimate of about 500 lives lost if speeds limits are increased to 65 mph on rural Interstates (Hoskin 1986).

The actual effects of states opting for a 65 mph speed limit will probably be smaller than estimated for 1988. As of June 1987, 28 out of the 50 states had increased rural speed limits, the state with the largest population, California, among them. Most of the states on the Atlantic coast have not yet increased speed limits to 65 mph.

Benefits of Higher Speed Limits

The principal benefit of the new 65 mph is its time saving. Assuming that all states ultimately increased speed limits, nearly 450 million hours of travel time will be saved by motorists and commercial drivers each year. This time saving is based on the difference between average speeds on rural Interstates and an assumed average speed of 65 mph on rural Interstates.

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2The TRB report estimated 630 lives saved on rural Interstates in 1974. Adjusting this figure for speed effects, other safety improvements, and travel results in an estimate of about 500 lives saved (630 x 0.85 x 0.736 x 1.33 = 525).
In addition to this enormous time saving, traffic police will not be put in the difficult position of trying to enforce a law that few obey literally. The new law allows the states to set speed limits at a speed most drivers on rural Interstates already comply with. The average 85th percentile speed on all rural Interstates across all the states is about 65 mph, though the variation on individual segments is quite wide.

If experience is any guide, however, motorists will in time adapt to the new limit; that is, they will continue to expect a 5 to 7 mph enforcement tolerance. Whether as many drivers nationwide will violate the 65 mph limit as the 55 mph limit is an open question at this stage, and unfortunately, the new law allowing states to raise limits to 65 mph does not require states to monitor speeds on rural Interstates. Early indications are that motorists will continue to expect an enforcement tolerance. Speed surveys conducted in New Mexico 9 weeks after the speed limit was raised indicated that half of passenger cars were exceeding 65 mph (Congressional Record, June 19, 1987). As discussed below, the lack of speed data uniformly collected across all states will undercut the ability of researchers to evaluate the effects of the 65 mph limit.

ALTERNATE APPROACHES TO SETTING MAXIMUM SPEED LIMITS

Three distinctly different approaches can be used to set maximum speed limits: the 85th percentile method, the identification of an optimum limit based on economic costs and benefits, and finally what the U.S. uses today, establishment of maximum limits by legislative compromise. I refer to this latter approach as an "incremental" method because it closely
resembles the method of small scale, incremental adjustments to policy described in Lindbloom's classic article on policy making in democracies (Lindbloom 1963).

The 85th Percentile Method
This approach, already described above, has gained nearly worldwide support by traffic engineers. The reasons are not surprising. First, it sets the speed limit at the level where most motorists are automatically in compliance, thereby greatly easing the enforcement burden placed on traffic police. Second, it has long been argued that setting the speed limit at the 85th percentile narrows the variability in speeds.

A few studies support the argument that a narrower variability in speeds reduces the frequency of crashes. Hauer (1971) has provided theoretical support and the empirical studies by Solomon (1964), Cirillo (1968) and the less well known research by RTI (1970) all suggest that the wider the variability of speed the more likely crashes will occur. The argument has considerable plausibility. As the differences in speed increase, motorists are more likely to be overtaking and passing each other, thereby increasing the probability of conflict. These empirical studies, though suggestive, have well known flaws. They all attempt to compare speed variability at the time of crashes to average speed variability. Judgments of the former, of course, are very difficult to arrive at after the fact and estimates of the latter tend to come from speed surveys in which little effort has been made to collect a random sample of speeds. Even if one sets the problem of random sampling aside, other problems remain. For example, the Solomon study mixed intersection crashes with rural highway crashes. One would expect a considerable speed
difference for vehicles involved in an intersection crash on a high speed rural highway. The Cirillo study corrected for this by only examining crashes on rural Interstates, (these highways have full control of access) and by eliminating crashes near exit ramps. A careful reexamination of the Cirillo study by Beatty (1972), however, showed that no statistically significant difference existed between the speed variability of vehicles involved in crashes and the speed variability reported for that same segment of highway. The RTI study did the best job of relating the speed of vehicles involved in crashes and relating that to the actual speed variability at the time (as measured by continuously operating speed monitors). The RTI study also suggested a relationship between the speed variability of vehicles involved in crashes and the speed variability on the same segment of highway, but the relationship was weaker than found in the other studies and the sample size was very small.

Thus, while there is some evidence that the 85th percentile both allows motorists to drive about as fast as they choose to and (to the extent that it narrows the distribution of speeds) appears to enhance safety, the evidence is far from conclusive.

Even assuming that crash frequency is reduced by reduced speed variability, the risk of injury and fatality increases as speed limits rise, because crashes become more severe--at an accelerating rate--as speed increases. This risk has been empirically demonstrated by O'Day and Flora (1982), and closely resembles the square power function one would expect from basic physics (Figure 4). Even if the 85th percentile reduces the frequency of crashes, as the speed limit is continually adapted to the speeds motorists wish to drive, and as speeds increase, the severity of the crashes that occur must increase.
The Optimum Speed Limit

In the early 1960's Oppenlander proposed an approach to setting speed limits that would minimize the total social cost involved (Oppenlander 1963). This approach, analogous to benefit/cost analysis, would seek the least expensive speed limit based on the cost of accidents, transport economics, comfort, time, and enforcement. Though this approach has conceptual appeal, many costs, not all of which are numerical, must be estimated (Joscelyn and Elston). The difficulty of doing so is illustrated in the different benefit/cost analyses of the 55 mph speed limit.

Clotfelder and Hahn (1978) provided a preliminary benefit/cost analysis of the 55 mph that tended to show that the benefits outweighed the costs. Nonetheless, they point out the difficulty of estimating the value of travel time, particularly travel on rural highways. Although estimates of travel time for work and commuting have gained some acceptance among analysts -- the range being between 20 and 60 percent of the average wage according to Altshuler's (1979) review -- most rural highway travel is for non-work purposes, and little consensus exists about the appropriate value for that time. The value of life, however, is even more difficult to estimate and widely different estimates are in use. For example, the estimates used within the federal government range from a low of about $500,000 in the Department of Transportation to $7 million at the Environmental Protection Agency (Miller 1987).

MacRae and Wilde (1979) point to additional difficulties with benefit/cost approaches. Their own preliminary assignment of an optimum speed limit, based on a benefit cost analysis, suggested that the optimum
speed was probably between 55 and 60 mph. Their analysis, however, stopped short on the question of feasibility. What speed limits, they ask, do drivers perceive as reasonable? What can be enforced? Although a lower limit may affect the aggregate distribution of speeds and have a positive effect on safety, even without gaining a high degree of compliance, disregard for the posted limit also imposes costs. Many of those opposed to the 55 mph limit argued that society should not, as a matter of values, pass laws that the public does not accept and obey. Because the value placed on reasonable laws, along with the value of time and the value of life, are the major issues at stake, and because of the difficulty of gaining consensus about the appropriate quantification of these values, policy makers are unable to rely on a benefit/cost approach alone for setting speed limits.

Incremental Method

The difficulty of weighing and trading off conflicting values in arriving at a policy decision is not unique to speed limit policy decisions. As Lindbloom (1963) pointed out, conflicts in values are characteristic of most important policy choices. Because values cannot be readily quantified, most of us have great difficulty trading-off values in arriving at complex choices. Decisions made by Congress are even messier for the simple reason that people in a pluralistic society such as the United States have different values.

As a result, policy decisions are not made all at once; instead, in democratic political systems policy is made and remade in a process of continual small adjustments. Lindbloom argues that these incremental
decisions are to be preferred because it is much easier to evaluate small changes in policy than to contemplate wholesale readjustments. In incremental policy making, one has the advantage of a string of successive small adjustments to compare future small changes to.

The decision of Congress to allow a maximum speed limit of 65 mph on only a segment of the highways previously posted at 55 mph fits within this framework for policy making, more or less as a natural consequence of the way complex way decisions get made. Given the genuine differences in value preferences that exist in society, it is hard to imagine that a decision about maximum speed limits -- one that explicitly trades off human lives for time and enforcement efficiency -- could be made any other way.

Lindbloom recommends the incremental method to policy making in part because it is possible to evaluate small adjustments in policy. One of the shortcomings of the most recent decision is the lack of foresight regarding data collection. In the past, the requirement that the states report speed data has served policy making well by providing researchers with one of the most basic sources of information needed for evaluating the effects of speed limits on safety. The states will no longer be required to report speed data on rural Interstates, therefore the next evaluation could be missing a critical element. Although some individual states will probably continue to monitor speeds, any evaluation of the 65 mph speed limit will have to pool data from several states in order to have a large enough sample of crashes to evaluate the effect, and will need to be able to compare the experience of states without higher speed limits. Being able to control for speed effects will be essential for drawing any meaningful inferences.
SUMMARY

Policy decisions about speed limits involve technical controversies and disagreements in society about the relative importance of different values. The central unresolved technical issue regarding speed limits is whether the 85th percentile rule-of-thumb, which has the advantage of setting the limit at the point where most drivers are automatically in compliance, is also the most effective safety policy. Supporters of the 85th percentile method have long held that by slowing down the very fastest drivers and by speeding up the slowest drivers the frequency of crashes would be reduced. The few studies of the relationship between speed variability of vehicles involved in crashes and the speed variability of vehicles on the highway suggest that this relationship is important, but the research is not conclusive.

The imposition of the 55 mph limit in 1974 reduced both the average speed and the variability of speeds and helped bring about a dramatic decline in traffic fatalities and injuries. The 55 mph maximum limit, which gained considerable compliance from motorists because of the energy crisis, may have been a unique experience. Without the additional impetus of the OPEC oil embargo, drivers may not have slowed down when the speed limits were reduced.

In any event, the slow erosion in compliance each year led the Congress to allow the states to increase maximum limits to 65 mph. Unfortunately, speed data will not be collected uniformly on rural Interstates. The TRB report estimates that a return to average speeds of 65 mph and a widening in the variability of speeds will contribute to 500
additional fatalities nationwide. But, what will happen to average speeds and the distribution of speeds? How well will motorists comply? How many deaths and injuries will result? In a few years policy makers will want answers to these questions when they begin debating demands for higher, or lower, maximum speed limits.

Even knowing the consequences of different speed limit policies, however, does not automatically lead to agreement on an optimum maximum limit. Such a decision depends on values in conflict, among them: safety, travel time, and the value of setting laws that most of the public respects and obey, along with values such as personal freedom and states' rights. While benefit/cost analyses have the considerable merit of requiring rigorous evaluation of these issues, the most important dimensions are values that are difficult, and probably impossible, to quantify.

Although the current approach to setting maximum speed limits is probably not terribly satisfying to traffic engineers or economists -- it has neither the simplicity of the 85th percentile method nor the rigorous quantitative dimensions of benefit/cost analysis -- it does require an open debate on important values. The push and pull of the political decision-making process results, at least for awhile, with a balance among competing values. The incremental adjustment from 55 mph to 65 mph will allow researchers to reevaluate the consequences of this decision and to inform the next round of debates on speed limit policy, provided, of course, that the necessary information can be collected.
FIGURE 1: AVERAGE SPEEDS ON INTERSTATE HIGHWAYS, 1972-1986

Miles per Hour

70

65

60

55

Rural

72 73 74 75 76 77 78 79 80 81 82 83 84 85 86

Urban

50

Year

FIGURE 2: CHANGE IN SPEED DISTRIBUTION ON RURAL INTERSTATE HIGHWAYS, 1973-1974

PERCENTAGE OF VEHICLES

40

35

30

25

20

15

10

5

0

35 40 45 50 55 60 65 70 75 80

SPEED (mph)

1974 (average = 57.6 mph)

1973 (average = 65 mph)

Source: TRB (1984)
FIGURE 3: FATALITY RATE TRENDS, 1968-1985

Fatalities per 100 million VMT

All Roads
Local Roads
Interstate

Year

68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85

FIGURE 4: PROBABILITY OF FATALITY FOR VEHICLE OCCUPANTS RELATED TO CHANGE IN VELOCITY

Probability of Fatality

Change in Velocity (ΔV) (mph)

Source: O'Day and Flora (1982)
REFERENCES


Congressional Record -- Senate. September 23, 1986, S13311.


UDC 656.053.2:656.13
614.86

Key words traffic control, speed limits, traffic safety

ABSTRACT

The speed-limit experiments in Finland continued from 1962 to 1978. A summary of the results of these experiments is presented in this publication.

In the 1960's temporary general speed limits were applied several times. During 1969-1973 experiments with recommended road-section speeds and after 1973 with compulsory speed-limits were carried out. The last mentioned experiment was extensive even by international standards.

The investigations proved that the number of accidents decreased the more the speed limits managed to reduce the speeds, which was a function of the relative level of the speed limit. Too high a speed limit could also raise the level of speeds and increase the number of accidents. This was the case for instance in adverse weather conditions on slippery road surfaces. alternative goals for the speed limit system are presented and the decision making concerning the speed limits reviewed.
THE SPEED LIMIT EXPERIMENTS ON PUBLIC ROADS IN FINLAND
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1. BACKGROUND

The first speed limit experiment was carried out in Finland by Professor Sauli Häkkinen as early as 1962 with clear and positive results. After about sixteen years and a number of investigations the political decision for a permanent speed limit system outside built-up areas was made on 5 May 1978. The political decision was complicated by the facts that

- suggestions of speed limits outside built-up areas raised violent protests in the motor magazines which were generally - and falsely - interpreted to reflect the general opinion,

- some of the experiments in the sixties were based on such limited material that no significant results could be obtained, which was interpreted as proving that the speed limits had no effect.

The speed limit experiments in the sixties, which make background for the studies in the seventies, are briefly presented in table 1. The speed limits applied in the sixties had one general level, and they were in force throughout the road network mainly during holiday periods.

Table 1. The speed limit experiments in Finland in the 1960s.

<table>
<thead>
<tr>
<th>Year</th>
<th>The speed limit used</th>
<th>The number of limit days</th>
<th>Relative level of speed limit</th>
<th>Effect on the mean speed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kmph</td>
<td></td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>1962</td>
<td>90</td>
<td>122</td>
<td>15</td>
<td>- 8</td>
</tr>
<tr>
<td>1963</td>
<td>90</td>
<td>25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1964</td>
<td>90</td>
<td>35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1966</td>
<td>90</td>
<td>61</td>
<td>25</td>
<td>- 10</td>
</tr>
<tr>
<td>1968</td>
<td>90</td>
<td>28</td>
<td>35</td>
<td>- 13</td>
</tr>
<tr>
<td>1968</td>
<td>110</td>
<td>14</td>
<td>5</td>
<td>- 2</td>
</tr>
</tbody>
</table>

The research concentrated on two objects: speeds and accidents. The speeds were measured with radar on good road sections and represented ideal traffic and road conditions. Accident studies were based on accidents reported by police.

Because of the controlled conditions the speed studies were easy to analyse and significant effects for the speed limits were noted each time the speed studies were made. Accident effects on the other hand only proved significant if the experiment had
been of sufficient duration (at least 50 days).

After four speed limit experiments it was decided to reject the temporary general speed limits after 1969, because the committee studying the experiment in 1968 deduced the speed limits to have no significant effect on the number of accidents. At that time Finland was one of the few countries in Europe having free speed on rural roads.

In order to avoid protests caused by the compulsory speed limits, experiments using recommended road section speeds were started in 1969 on some of the main routes. The drivers were informed about the desired speed of the road section and it was voluntary to follow the information. Meanwhile the earlier decision of rejecting the general speed limits had raised scientific criticism.

A reanalysis made with the material from the sixties shows surprising stability in the effects of the speed limits (Fig. 1).

![Figure 1. Effect of the speed limit on accidents as a function of the change in the mean speed in the experiments in the 1960s.](image)

Early in the 1970s the number of fatal accidents reached the same absolute level as that in Sweden, where exposure was about three times as great as in Finland. A second committee was set up in 1970 which catalogued the experiments made in other countries with speed limits.

Subsequently a large scale speed limit experiment was introduced in 1973 for three years. The experiment was based on differentiated road section speed limits on the main roads (as with the recommended road section speeds earlier) and a general so-called base-speed limit on the secondary road network. (Reminiscent of the earlier temporary speed limits.)

The goal of this last experiment, which was finally reported in March 1978, was to further clarify the problem and provide the
basis for political decisions.

2. EXPERIMENTS WITH RECOMMENDED ROAD-SECTION SPEEDS

The experiments using recommended road section speeds took place over three years on five main routes in Southern Finland amounting a total of 150 kilometres. In the first phase the recommended speeds were in force on three of the roads and control observations were made on the two other roads, on which speed was left free. This phase lasted two years. In the second phase the speed recommendations were transferred to the former control sections and the earlier recommended-speed routes had free speed. This phase lasted one year.

The three experimental routes were chosen on the basis of their accident risk. The routes for comparison were chosen to reflect the properties of the other three as much as possible, except for this accident risk level.

The studies took into account the characteristics of the traffic flow, the number of accidents reported by police, and the drivers knowledge and opinions about the recommendations. The traffic flow characteristics were observed by speed measurements using radar. The speeds were observed systematically on a monthly basis at 16 observation stations between 1.6.1970 and 30.6.1973. In total, some 200,000 individual speeds were observed. Accident analysis was based on about 1000 accidents taking place on the five routes during the period from 1.1.1968 to 30.6.1973. The interview studies about the knowledge and opinions of the drivers took place in 1969 and 1970 on the recommended roads and amounted to about 400 interviews each. In 1973 a postal survey was made with a panel of 2000 driving-licence holders.

The benefits and limitations of the study are tied to its experimental design. It was voluntary to follow the recommended speeds. Hence it is necessary, when anticipating positive effects, that the drivers accept and understand the recommended speeds. If the system is accepted changes in behaviour can be expected. The positive effects on traffic safety are, according to the hypothesis, based on decreased speeds or in other words, on changed behaviour. The methodology used makes it possible to follow the above mentioned logical chain. The reliability can be studied with reference to the reversal of the changes when removing the recommendations.

The limitations depend firstly on the fact that the experiment roads were subjectively chosen from those with exceptionally high accident risk. This is a major limitation in generalising the effect. It is obvious that the effects received are the maximal, and that an extension of the experiment to roads representative of the whole road network in terms of risk would give different values. Secondly the experiment was too limited to result in detailed quantitative effects and, for instance, to make it possible to combine the effects on the traffic flow with
those on the number of accidents. Thirdly the experiment with the recommended road section speeds proved to only remain an episode between periods of disbelief and belief in speed limits.

The main result of the experiments with recommended maximum road section speeds was that the severe accidents resulting in death or injury decreased significantly irrespective of the road conditions. On dry road surfaces the number of accidents always decrease, however less in the group of minor accidents with only material damage. But if the road surface is slippery, a frequent occurrence in Finland, the minor accidents increase with a 95 percent level of significance.

On the average the decrease of the mean speeds was about 2 kmph and the total number of accidents decreased by 10 percent, which consisted of a 25 percent increase of accidents resulting in only material damage and a 46 percent decrease of fatal and injury accidents.

3. THE SPEED LIMIT EXPERIMENT DURING 1973 - 76

The three year speed limit experiment was started on the 1st of August 1973 and had four phases:

- phase 1 from 1 August to 20 December, 1973 concerned the main roads in Southern Finland amounting to 5000 km (7 percent of the public roads and 30 percent of the vehicular mileage driven). The speed limits were differentiated with values 60, 80, 100 and 120 kmph.

- during the period from 21 December 1973 to 30 June 1974 Finland had a general speed limit of 80 kmph caused by the so called "energy crisis" (Phase 2).

- the 3rd phase with differentiated speed limits was begun at the end of the general speed limit and lasted one year. Differentiated speed limits were enforced on 15,000 km, amounting to 60 percent of the vehicular mileage driven and about 20 percent of the length of the national road network. The rest of the road network, 58,000 km of secondary roads got a general speed limit of 80 kmph, the so-called base-speed limit.

- the 4th phase of the differentiated speed limits was started on 1 July 1975 and ended on the 30 June 1976. The speed limit system was generally like the 3rd phase with minor changes made for research purposes.

The experiment was mainly planned according to orders from the Ministry of Transport without any attention paid to the research. That is why the experiment had to be designed mainly as a before - and - after experiment. In the first phase there was a chance to compare the limited parts of the road network with the rest of roads which had free speed. Because of varying speed limits it was possible on some roads to follow the recursive variation of the limits, for example free speed - 100
kmph - 80 kmph - 100 kmph - 80 kmph.

Only once, when pure research reasons caused changes in the speed limit system, was there a statistical experiment with 60 kmph speed limits on the secondary road network. The experimental roads having 60 kmph speed limits were randomly chosen from matched pairs of roads with 80 kmph base-speed.

When analysing the before - after experimental design a logical sequence was formed for causal conclusions. Firstly, the average change in the number of accidents was noted from before to after. The respective changes in speed distribution were recorded, based on systematic measurements at about 100 observation stations randomly chosen and representing the distribution of vehicular mileage on the road network. The total number of observations was over 500,000 and the number of accidents in the analysis over 74,000.

Secondly, the dependent variables were analysed with multiple variable methodology in order to check that no other known factor caused that part of the average change in the dependent variable, which had the form of linear transformation. The results of these analyses can be interpreted as follows: There was a change in the number of accidents and the speeds which had the form of linear transformation and which took place where and when the speed limits were introduced.

Finally the selective linear effects on traffic flow and accidents were combined. To be interpreted as an effect of speed limits the decreased number of accidents ought to be explained with respective changes in speed. The results were confirmed by the separate experimental design described above.

The speed limit experiment was a study involving twenty-five man years which in addition to the main project described above, consisted of nine separate investigations into the effect of the traffic flow characteristics, such as platoons, weekend traffic, choice of route and trafficability, speeds during the night, and so forth. On the accident side of the study separate projects were directed, for instance in order to analyse the effects of increased enforcement, variations of propaganda etc.

The experiment with recommended road section speeds had shown that the effect on accidents could be both positive and negative.

The same kind of phenomenon was observed in the compulsory speed limit experiment. There are qualitatively three kinds of effects of the speed limits depending on what kind of effects they have on driver behaviour. These effects are described in Figure 2. Here the level of the speed limit is compared with the speed distribution in the event that drivers could freely choose their speeds.

In case (a) the speed limit is set above the 85th percentile of free speeds. Very few drivers have to decrease their speeds. But
those who themselves would choose a lower speed than the limit set, do their best to follow orders and increase their speeds. This was particularly true with inexperienced drivers. Those who had held a driving licence less than one year accelerated their mean speed by 11 kmph from 67 to 78 kmph when the base speed limit 80 kmph was introduced.

Figure 2. The effects of the speed limits depending on their level.

In case (a) an increase of mean speeds and a decrease of standard deviation are noted. The total number of accidents is increased because of the increase in minor accidents. The number of severe accidents is unaffected.

In case (b) the speed limit is at the 85th percentile of free speed. In this case 15 percent of drivers are expected to lower their speeds. At the same time that the speeds at the top of the distribution are decreased the speeds on the other end are increased. The mean speed remains the same but the standard deviation is decreased. The total number of accidents is unaffected but the person-damage accidents are decreased.

In case (c) the level of the speed limit is lower than the 85th percentile of free speeds. The highest speeds are decreased which even can be observed at the mean speed level. When the speed limit is set so low that it is at the 50th percentile of the free speeds there seem no longer to be any difference in the relative decrease of severe and light accidents. The mean effects of the speed limit system as observed in the studies are presented in Table 2.

The change in the number of accidents as a function of the change of the mean speed is presented in Figure 3. The fits described explain about 80 percent of the percentual change in accidents and they pass exactly through the origo, which means
that no change of mean speed gives no change in the number of accidents.

Table 2. The effect of the speed limits on speeds and accidents.

<table>
<thead>
<tr>
<th>Type of road system</th>
<th>Road speed limit</th>
<th>Relative level of speed limit</th>
<th>Effects on speeds</th>
<th>Effects on accidents</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>mean speed dev.</td>
<td>person total dam.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>kmph</td>
<td>%</td>
</tr>
<tr>
<td>Differentiated</td>
<td>60</td>
<td>35</td>
<td>-2</td>
<td>-2</td>
</tr>
<tr>
<td></td>
<td>80</td>
<td>45</td>
<td>-5</td>
<td>-6</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>20</td>
<td>-2</td>
<td>-5</td>
</tr>
<tr>
<td></td>
<td>120</td>
<td>5</td>
<td>+2</td>
<td>-2</td>
</tr>
<tr>
<td>General</td>
<td>60</td>
<td>35</td>
<td>-2</td>
<td>-2</td>
</tr>
<tr>
<td></td>
<td>80</td>
<td>45</td>
<td>-6</td>
<td>-6</td>
</tr>
<tr>
<td></td>
<td>100*</td>
<td>65</td>
<td>-7</td>
<td>-8</td>
</tr>
<tr>
<td></td>
<td>120*</td>
<td>70</td>
<td>-9</td>
<td>-8</td>
</tr>
</tbody>
</table>

*) During the general speed limit 100 and 120 kmph speed limits were lowered to 80 kmph.

Figure 3. Change in the number of accidents as a function of change of the mean speed. (\(A_p\) = person damage accident, \(A_T\) = total number of accidents)

4. THE DEVELOPMENT OF TRAFFIC SAFETY IN FINLAND

In the beginning of the 1970s the yearly number of fatalities in road traffic accidents in Finland was about 1200. During ten years the number was lowered but this development stopped in the beginning of 1980s. During this decade the number of fatalities has varied between 500 and 600. The role of speed limits in the
positive development during the 1970s is described in figure 4, where we examine the result of the multivariable analyses.

Two curves are compared: The number of fatalities on public roads and the forecast figure, obtained assuming that it would have followed the development of vehicular mileage after 1972. The shaded area between the curves has been obtained by adding to the real number of fatalities the influence of speed limits obtained as a result of the analyses. The annual number of fatalities would have remained within this area if no speed limit experiment had taken place.

![Diagram showing the number of fatal accidents on public roads, forecast based on growth in vehicle mileage, and the calculated effect of speed limits.](Diagram)

**Figure 4.** The number of fatal accidents on public roads, forecast based on growth in vehicle mileage, and the calculated effect of speed limits.

If no traffic safety improved measures had been taken during the experimental period, the probability of accidents would have remained at the level of 1972. Then the number of fatal accidents would have increased with increased traffic volume. The difference between the upper curve and the shaded area is of about the same magnitude as the influence of the trend variable in the models. Consequently the result of multivariable analysis is logical.

5. **HOW THE RESULTS OF SPEED LIMIT INVESTIGATIONS WERE UTILISED**

The benefits of the speed limits are won by decreased number of accidents and lower vehicle costs. We cannot, however, go on lowering the speed limits until the traffic is stopped in order to minimise the number of accidents. There must be a balance between the costs and the benefits of speed limits. The most
important cost is increased travelling time.

The level of speed limits is an implicit expression of evaluations of time and safety in the society. In order to gain the optimal level of speed limits we must define explicit values for time unit and accident costs giving a political value for the human suffering. The use of resources is optimal if the same values are used when calculating the benefits and costs of a road investment and setting the speed limit level.

In Finland we defined three objectives for the speed limits:

1) The speed limits must not increase the number of accidents.

2) The speed limit system shall not be incompatible with the society's evaluation of time and accidents.

3) Within the limits of the above conditions, the speed limits shall regionally and temporally be differentiated according to traffic safety.

To reach the defined three goals extensive changes would have been needed in the speed limit system:

1) The most general road section speed limit 100 kmph should be reduced on about 50 % of the road length, where it was imposed, either to 90 or 80 kmph. The change would affect about 5000 road kilometres.

2) The base speed limit of 80 kmph valid on the main part of the public road network (70 %), and which covered about 40 % of the vehicular mileage, should be reduced to 70 kmph. The change would affect about 53,000 road kilometres. A part of this road network could, however, be incorporated in the road sectional speed limits higher than 70 kmph (about 10,000 km).

3) During October - February the 100 kmph speed limit should be reduced to 80 kmph.

4) The speed limit of 120 kmph, which is used on motorways, should be abandoned under all conditions.

None of these suggested changes were carried out.

Now in 1987 when almost 10 years have passed since the results were published in Finland the Minister of Transport has given the Roads and Waterways Administration orders to carry out an experiment with lower speed limits in winter and higher speed limits in summer.
Speed Limits and Accident Consequences and Risks

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Sweden

ABSTRACT

The speed concept concern nearly all aspects on the traffic safety situation. In order to regulate speeds knowledge of the relationship between speeds, accident consequences and injury risks is very important.

This paper gives same data on speed behaviour on different kind of roads/streets with different speed limits.

For roads/streets with different speed limits the accident consequences and risk situation is described for different accident situations.
0. Speed and traffic safety - Introduction

The three components forming the road transport system, the road, the vehicle and the driver, together have a speed potential which is higher than the highest speed limits and also of course considerably higher than the lowest limits in urban areas.

While car drivers in general accept speed restrictions, the actual level accepted varies among them.

Speed restrictions are often based on traffic safety ground, even if their introduction in certain countries is related to today's energy considerations or tomorrow's environmental situation.

The debate around speed limits has in many cases resulted in a bargaining with killed and injured in traffic as stakes.

If, for example, one of the above components is improved for traffic safety reasons, there will often be a demand for increased speed limits or a reduction in penalties for speed limit infringements.

Experience from changes in speed behaviour, generally in connection with speed limit changes, has shown that small differences in journey speeds exert a large effect on traffic accidents and traffic casualties.

The effect in the number of killed is significant in that a certain change in speed has a greater effect on the number of serious accidents than it does on minor accidents. One explanation is that accident situations on the average result in less serious accidents when speeds are reduced, the opposite being true when speeds increase.

Very few drivers who express their opinions on speeds and speed limits think that the limit is too high. Their opinion is that the speed limit is too low for the conditions in which they drive. In the debate, however, the concepts of speed and speed limit become confused, and consequently it is thought that if the speed limit is raised by 10 km/h, speeds also increase by 10 km/h. This is not the case, since the choice of speed depend on several other factors. The majority of drivers are much more sensible than the speed limit system.
1. Speed measurements and the occurrence of different speeds

In recent years, the problem of speed in traffic has become evident. In the current debate, it is primarily the poorer conformance with applicable speed limits that is the subject of discussion. The results of the VTI's speed measurements form a significant part of the basic information in discussions of conformance with speed limits. The principal reason for this is that the VTI's measurements make it possible to analyse the trend in speed for a number of different groups of road environments since the mid-70s.

The speeds at each measuring site are recorded during a 24-hour period and are repeated at intervals of one year and on the same day of the week. At certain measuring sites, speed measurements have been made several times each year and in other cases at intervals of several years. The number of measuring sites has been increased successively up to 1986 and there are now 40 sites where speed measurements have been made on at least two occasions in different years. Apart from vehicle speed, the measuring equipment used also records vehicle type and headways.

Using the speeds obtained from these measurements, different types of speed analyses are then made. However, a major problem in the connection is that the speeds demonstrate considerable variation. Despite this, there are advantages in attempting to summarise the results in as few values as possible.

Figure 1 contains a histogram of measured speeds. Using a distribution of this nature, it is possible to state the number of vehicles driving faster or slower than a given speed or the number of vehicles whose speeds are within a certain speed range. A condition is that the number of registered vehicles is small.
Figure 1. Histogram of measured speeds.
2. Speed distributions — median speeds, mean speeds and journey speed

Where large volumes of data occur, the empirical distribution function of measured speeds is used instead. Since we cannot directly calculate how many vehicles drive faster than the speed limit, we indicate instead the proportion of all recorded speeds that are for example, higher than the speed limit. The speed distribution shows directly how the recorded speeds are distributed among the various speed ranges.

Traditionally, the speed that is overrun or underrun by half the vehicles — the median speed — is documented and used as the basis for comparisons.

However, since the speeds normally demonstrate a large variation, the median speed is usually accompanied by a measure of the speeds of "offenders", e.g. the speed exceeded by 15% of the vehicles (85% drive below this speed) and a corresponding measure for those driving slowest of all — e.g. the speed underrun by 15% of the vehicles. The former is termed the 85 percentile of the speed distribution and the latter the 15 percentile. See Figure 2.

Another way of recording speeds is to calculate mean speed and standard deviations. Unfortunately, these measures are sensitive to extreme values.

A third way is to measure journey times over a known distance. The journey time measurements can then be converted to median journey speed or, more usually, to mean journey speed. If the measurements relate to longer distances, evaluation becomes very extensive since each individual vehicle must be identified often on the basis of film or registration number observations. The extent of journey time measurements is therefore very limited. Nothing has been done in the way of journey time measurements aiming at following the speed trend but these may be carried out in the future.

Further descriptions here are based on empirical speed distributions from which median speeds etc can be derived.
$V_{50}$ Median speed = The speed overrun or underrun by half the vehicles

$V_{15}$ 15 percentile speed = The speed underrun by 15% of the vehicles

$V_{85}$ 85 percentile speed = The speed underrun by 85% of the vehicles

Figure 2. Speed distribution function. The speed underrun by a given proportion of total vehicles.
3. Speed Limits and Speeds

Figures 3 and 4 show the approximate speed distributions for different types of roads. The results are based on mean values from different measurements performed by the VTI. Figure 3 records speed distributions from 4 different urban environments. Figure 4 shows speed distributions for 6 different rural environments. The points on the speed axis are median speeds. The 15 and 85 percentile speeds are indicated correspondingly. It is interesting that the speed distributions are generally parallel. If it is assumed that the ranking of vehicles with regard to speed is the same in different road environments, this would indicate that the change in speed from one environment to another is the same for all vehicles, at the same time as the speed present at the outset are maintained.

As can be seen, the speeds vary between different environments. It may also be noted that the variation expressed as the difference between the 85 and 15 percentiles is in the order of size of 20 km/h.

In the case of the relation between speed and traffic safety, there is a clear influence of speed level on accident risk. Often it is stated that it is not the speed level that is the problem, but the variation in speeds.

However, a large part of the variation in speeds within a described road environment lacks significance since the speed distributions cover the entire day (24 hours). The majority of the highest and lowest speeds occur at different times of the 24-hour period. The highest speeds occur on light traffic and the lowest in heavy traffic. In fairly high or normal flows, the variation in speeds is small. Calculations of the median speed for periods of 1 hour during 1 day show that the differences in median speed is in the order of size of 10 km/h between light traffic at night and the hours with the heaviest traffic during the day (24 hours). Purely generally, it can be stated that if the variation in percentile speed will also increase. If the variation in speeds decreases, the median speed will decrease and so on.

Consequently, there are serious problems in clarifying and measuring the effects at macro level which are due to changes in speed level and variation in speed. Changes in the median speed can be regarded as a collective measure of both the effects in speed changes.
Figure 3  The results from 24-hour speed measurements in an urban area. Cars.

Figure 4  Results from 24-hour speed measurements in a rural area. Cars.
4. Statistics for accidents involving personal injury and relating to different road categories and speed limits.

The official statistics for accidents involving personal injury show that the number of such accidents reported by the police has increased in recent years. If the accident statistics is distributed according to speed limits, the same accident trend can be seen as for road sections with different speed limits. At the same time, traffic during 1980-85 has increased by 5-6%. See Figure 5. The fact that accidents involving personal injury are increasing even faster than the increase in traffic is of great concern. A realistic hypothesis is that the effect of traffic safety measures implemented so far has been eliminated by changed behaviour in traffic including a higher speed level. The significance of the speed increase is indicated by the dramatic increase in road traffic fatalities in recent years.
Figure 5  Mean annual number of accidents involving personal injury according to speed limit for two-year periods during the 80s.
5. Distribution of traffic according to different speed limits

According to the study of travel habits made by the Central Office of Statistics, cars accounted for approximately 50,000 million vehicle kilometres in Sweden during 1985. Figure 6 shows a general distribution of traffic according to the different speed limits 50, 70, 90 and 110 km/h.

![Diagram of vehicle mileage distribution]

**Figure 6** Distribution of vehicle mileage according to speed limits 110, 90, 70 and 50 km/h.

More than half the traffic mileage on 110 km/h roads was on motorways. A total of 13% of the traffic mileage was on 110 km/h roads, 30% on 90 km/h roads, 24% on 70 km/h roads and 29% on 50 km/h roads.
6. Fatal accidents

Using the official accident statistics and estimates of traffic volume on roads/streets with different speed limits, the risk of a fatal accident can be calculated per thousand million vehicle km. Figure 7 shows the number of fatal accidents per thousand million vehicle km for 110 km/h sections of motorways, other 100 km/h sections, 90 km/h sections, 70 km/h sections and 50 km/h sections.

Figure 7 Vehicle mileage in thousand million vehicle km

In addition to the risk of a fatal accident, the diagram shows the approximate number of fatal accidents per year. The difference in the risk of a fatal accident is small between various types of road environments, with the exception of the low risk on motorways with a speed limit of 110 km/h. One conclusion is that the increase in standard of two-lane roads and simultaneous increase in the speed limit to 100 km/h have not contributed to reducing the number of fatal accidents.
7. Risks of accidents involving serious personal injury, including fatal accidents.

Figure 6 shows the number of fatal accidents and accidents involving serious personal injury according to different speed limits.

**NUMBER OF FATALITY AND SEVERE INJURY ACCIDENTS PER BILLION VEHICLEKILOMETER**

![Bar chart showing accident rates](chart.png)

Figure 8. The risk of an accident involving serious personal injury (including fatal accidents) for road sections with different speed limits.
Unlike the risks of a fatal accident, the large difference can now be seen in accident risks between different road environments. The poorer the road environment, the greater the risk of an accident involving serious personal injury. A large part of the differences in road environment consist of the occurrence of junctions and unprotected road users, which greatly contributes to the difference in the accident risks described. The fact that the 50 km/h sections have such a high risk of accidents involving serious personal injury is linked to collisions between vehicles and pedestrians or cyclists.
B. Risk of accidents involving personal injury

2 out of 3 accidents involving personal injury in the official traffic accident statistics involve only slight injury. Figure 9 shows the total risk of an accident involving personal injury - the number of accidents involving personal injury per thousand million vehicle km.

Figure 9. Risk of an accident involving personal injury according to different speed limits.

As the diagram shows, the difference between environments is greater when all accidents involving personal injury are included in the calculation of accident risks. Half of all accidents involving personal injury occur on 50 km/h sections.
In many cases, these latter 50 km/h sections consist of local speed limits on 70 km/h and 90 km/h roads. If these accidents were to be linked to the general speed limit, the difference in accident risk would be reduced, although not to any notable degree.

We know today that the lower the speed limit, the poorer conformance becomes. The accident risks show the same pattern, which in itself indicates the importance of lower speeds than could be obtained through better conformance to the speed limit in order to reduce the highest accident risks. The latter applies regardless of whether it relates to a local speed limit in the country or a 50 km/h limit in an urban area.
9. The consequences of accidents

From the various calculations of accident risks, it can be seen indirectly that the higher the speed limit, the more serious the accident. Figure 10 demonstrates this fact for various types of road environments in the form of the proportion of fatal accidents among all accidents involving personal injury.

PROBABILITY THAT AN INJURY ACCIDENT RESULTS IN A FATALITY ACCIDENT IN DIFFERENT TYPES OF ROADS - 1985

Figure 10 The probability that an accident involving personal injury will result in a fatality in various traffic environments - 1985.

The diagram shows that some environments, dual carriageways and normal two-lane roads with a 110 km/h speed limit as well as private roads with a 70 km/h speed limit have a very high proportion of fatal accidents. This is largely explained by the relatively high frequency of head-on accidents in these road environments, an accident type that often leads to very serious consequences.
Among the road environments are also dual carriageways and motorways with speed limits of 90 and 70 km/h. All in all, there is a clear relation between highest permitted speed and the proportion of fatal accidents and the proportion of accidents involving serious personal injury respectively. The higher the speed limit, the more serious the accident.
10. Icy/snowy roads and darkness

Finally, the official traffic accident statistics also include information on icy/snowy road conditions or darkness in connection with accidents. Figure 11 shows the proportion of accidents in conditions of ice/snow or darkness and the proportion of accidents in darkness in relation to total accidents involving personal injury.

PERCENTAGES OF INJURY ACCIDENTS ON ICE/SNOW RESP. IN DARKNESS OF ALL INJURY ACCIDENTS - DIFFERENT ROADS AND SPEED LIMITS.

Figure 11 Proportion of accidents involving personal injury in conditions of ice/snow or darkness in relation to total accidents involving personal injury - different environments and speed limits.
The proportion of accidents in condition of ice/snow or darkness is higher on roads with higher speed limits than on roads with low speed limits. Both these conditions often demand conformance to speeds lower than the permitted speed. There is therefore much to support lower speed limits during the dark part of the year, which also apply during the part of the year when conditions of snow and ice occur.
11. Accident and Injury Risks for Different Accident Situations

In the next pages the accident and casualty situation in Sweden 1985 described for different accident situations and roads/streets of different types and speed limits.

The figures show the risk situation — injured per $10^9$ vehicle kilometers distributed on fatalities, severe injuries and slight injuries.

The areas are proportional to the number of injuries reported by the police.

The total injury problem = RISK X EXPOSURE

Through the figures it is possible to identify high risk accident types or situations.

For an average driver in Sweden the injury risk for single accidents (no other vehicle or road user involved) is almost the same all over the road network.

Among multi-vehicle situations the highest risks concern injured in intersections when vehicles are approaching from different roads/streets in urban areas.

Head-on collisions has relatively high risks on high-speed two-lane roads and two-lane roads of low standard.

The risks for rear end collisions and the corresponding situations when the vehicle in front or both vehicles are turning are highest in urban areas.

Of all accident situations the most risky situation for a car driver is to collide with a pedestrian, cyclist or mopedist in urban areas.
POLICE-REPORTED INJURED IN SWEDEN 1985 IN
DIFFERENT ACCIDENT SITUATIONS

INJURED PER 10⁹ VEHICLEKM.

SINGLE-VEHICLE SITUATIONS

ACCIDENT CONSEQUENCE
- KILLED
- SERIOUSLY
- SLIGHTLY

SPEED LIMIT

RURAL ROADS
- MOTORWAY
- HALF MOTORWAY

URBAN ROADS
MULTI-VEHICLE SITUATIONS

INJURED PER $10^9$ VEHICLEKM.
"Speed Limit in Rural Areas in Denmark 1973-1986"

by Hans Lund, civil engineer
Danish Council of Road Safety Research.

Abstract

The paper will describe results from speed measurements carried out on a two-lane rural highway and on a motorway every summer in the years 1973-1986.

The series consist of short time measurements with a duration of 1-4 hours taken on different days of the week and covering different hour intervals of the day.

The speed results will be compared with the actual speed limit and - if possible - with the accident frequencies for the two road types.

During the period, the speed limits has been changed several times. In the summer of 1973 the choice of speed had no set limit, but severe limits were imposed during the winter 1973/1974 as a reaction to the oil supply crisis. These limits were relaxed slightly in the spring of 1974 and then remained unaltered until 1979, when they were again lowered, in response to the new oil crisis, to the level which since has been in force.

In 1985 the speeds may have changed as a result of public discussion about new speed limits on motorways.
Speed Limit in Rural Areas in Denmark 1973-1986

by Hans Lund, civil engineer
Danish Council of Road Safety Research.

Introduction.
In this paper I will describe the speed limits on rural roads in Denmark and give some results from two series of speed-measurements. These measurements have been carried out every year since 1973 on the same measuring sites and at the same time and day of week.

Speed limits in Denmark.
From the beginning of this century when the first traffic act was given, there have been speed limits in force most of the time. For a long period from 1932 to 1953 the limit for ordinary cars was 60 km/h and 50-30 km/h for vans and lorries.

In the beginning of the fifties the number of cars increased and the technical standard of the cars improved, so that the limit of 60 km/h was felt very low. The police did not have the necessary equipment and manpower to enforce the speed limits and in 1953 the limit for cars was repealed. In the traffic act from 1955 it was said that the driver should adapt the speed to the actual driving situation, i.e. traffic density, weather, road surface. For heavy vehicles the speed limit remained, but the level has been raised several times up to the 70 km/h in force since 1973.

In 1961 to 1964 temporary speed limits were used as a remedy against the severe traffic accidents in periods with dense traffic. The limits were 80 km/h on rural roads and 100 km/h on motorways. However the effect of these speed limits was not very clear. In a report
from 1970 The Danish Council of Road Safety Research concludes that there was no clear conclusion of the effect of the temporary speed limits in Denmark.

As a result of the oil supply crisis general speed limits were introduced during the winter 1973/1974. In the winter they were set at 60 km/h in urban areas and 80 km/h on rural roads. With the lower speed, a decrease in traffic accidents immediately followed. The Danish Parliament therefore decided that the speed limits should be in force two more years, and that the Danish Council of Road Safety Research should analyse the effect of the limits, which were changed to 90 km/h on rural roads and 110 km/h on motorways in the spring 1974.

In the report from 1975 the Council concluded:
Comparing one year before with one year after it can be seen that there is a clear reduction both in traffic accidents in urban areas and on rural roads. This reduction is highest for accidents involving two motor vehicles, but also accidents with light road users and a motor vehicle was reduced. This change can very unlikely be explained by a change in traffic volume, but the decrease in the measured speeds seem to explain the reduction.

The speed limits were unchanged until 1979 when the limits were reduced by 10 km/h to 80 km/h and 100 km/h outside built-up areas. This again was done not because of traffic safety, but as a result of the second energy crisis. The gasolin prices increased significantly that summer.

In the spring of 1984 it was suggested that the speed limit on motorways should be raised. This time the following discussion in the parliament focussed on
traffic safety and the whole speed limit system was again reconsidered. The result of the very intense debate was that:
the speed limit on motorways remained at 100 km/h,
the speed limit on rural roads remained at 80 km/h
but in urban areas the speed limit was decreased from 60 to 50 km/h.
Local speed limits in urban areas using road signs could be lower or higher than the general speed limit.

Speed measurements in Denmark.
The Danish Council of Road Safety Research used speed measurements in an investigation in 1969 - 1971 on the effect of police enforcement. The measurements were made as a time registration over a short distance of app. 30 - 40 meter using detector loops.

In the summer of 1973 it was felt necessary to carry out a series of short-time speed measurements to be able to answer questions about the general speed level on (a few) rural roads.

After the investigation of the effect of the oil crisis limits where the measurements were repeated, the Council found it necessary to continue the speed measurements in a reduced form, and this has been done on two sites since then.

The measurement sites.
To illustrate the roads figure 1 shows the measurement site at Sorø. This road is a two-lane rural highway app. 70 km. west of Copenhagen. This road carries the traffic crossing the Great Belt and also local traffic. Measurements are only carried out in direction west (from Copenhagen). Along the road there are bicycle paths in both sides.
Figure 1: The measurement site at Sorø app. 70 km west of Copenhagen. Rural national highway.

Figure 2: The measurement site at Gl. Holte app. 20 km north of Copenhagen. Rural motorway.
The next figure 2 shows our measurement site on a rural motorway app. 15 km north of Copenhagen. The traffic consists of local traffic going to and from Copenhagen, but also traffic to Sweden via Helsinore. Only traffic going north is measured. The results later are given for each lane.

Results
The measurements at Sorø are carried out on 3 different weekdays:
tuesday from 10 to 11 am,
Wednesday from 3 to 5 pm,
Wednesday evening from 7 to 9 pm,
Thursday morning from 10 to 12 am,
Thursday afternoon from 4 to 6 pm
and Sunday afternoon from 1 to 3 pm.
The measurement technique gives us the possibility to separate cars according to their length, but in this paper the results are from all vehicles categories.

Mean values of the speeds from every single measurement are shown on figure 3. The number of measured cars in each measurement varies in 1986 from 514 to 1213 cars. The figure shows a clear decrease in speed in 1974 compared to 1973 and again in 1979 compared to 1978. In the years 1974 to 1978 and again from 1979 to 1986 a slight increase in mean speed can be seen. Because of the variation in mean values from the single measurement, it is not easy to see characteristics from these measurements, but mean value from the measurement carried out on Wednesday evening is higher than the others.

Mean values from these 6 measurements are shown on figure 4. The slight increase in mean speed after 1979 seems to fade out in 1985-86.
Figure 5 shows the proportion of drivers exceeding the speed which is in force to day, 80 km/h. The figure shows mean of 6 measurements and the shape of the figure is similar to the figure showing the mean speed. It can be seen that 40% exceed the speed limit in 1986. In 1973 over 60% exceeded 80 km/h.

The measurements on the motorway is carried out on the following days and time intervals:
Friday morning from 8 to 10 am,
saturday morning from 9 to 11 am,
monday morning from 10 to 12 am,
monday afternoon from 4 to 6 pm and
tuesday morning from 10 to 11 am.

Figure 6 shows how the mean values from the 5 measurements has been in the two lanes. In 1986 the numbers of measured cars in the right lane varies between 621 and 2305 cars and in the left lane between 375 and 3473 cars. In the right lane it can be seen that after 1977 the mean speed is higher than in 1973. Two characteristic drops in mean speed can be seen: from 1973 to 1974 and from 1978 to 1979. The latter may be explained by a high value in 1978. The slight increase in mean speed - app. 1 km/h/year - seems to fade out in 1984-1986.

In the left lane the decrease in mean speed from 1973 to 1974 and from 1978 to 1979 are bigger than in the right lane. In the years 1974 to 1978 and 1979 to 1983 the mean speed increases sligtly. In 1984 the mean speed jumps a bit higher than expected, but remains on that level in 1984 to 1986. The mean speed in the left lane is still in 1986 below the mean speed of 1973.

Figure 7 shows the difference in mean speed in the left lane and in the right lane. In 1973 this difference was as high as 25 km/h and the lowest value
is found in 1981. In 1986 the value is above 15 km/h.

Figure 8 and 9 show trends and mean speeds in the two periods 1974-1978 and 1979-1986. The yearly increases in the right lane are 1.6 km/h/year in 1974-1978 and 0.7 km/h/year in 1979-1986. In the left lane the yearly increases are 1.9 km/h/year and 1.1 km/h/year.

Looking at the percentage of drivers exceeding the actual speed limit, figure 10 shows the increase in this percentage during the years 1974 to 1986 on the rural national highway. The figure shows an almost constant increase in the percentage of illegal drivers. If you are very optimistic, you might say that in 1984 stopped this increase at a level of 42 %.

Considering the motorway, figure 11 shows for left and right lane the percentages of drivers exceeding the speed limit on motorways, which was 110 km/h from 1974 to 1978 and 100 km/h after 1978.

Considering the period 1974 to 1984 it seems that there has been an increase in the percentage of illegal drivers. The increase is highest in the left lane. In 1984 this increase stopped and the percentage has been almost constant since then.
Concluding remarks.
The speed measurements described above result in the following positive remarks:
- on the national highway the mean speed today is lower than before speed limits were reintroduced in 1973
- and the percentage of drivers exceeding 80 km/h is app. 30 % lower now than before speed limits were reintroduced.
- on the motorway the mean speed in the left lane today is lower than before speed limit was introduced in 1973
- and the difference between right and left lane is smaller now than before speed limit.
- the yearly increase in mean speed seems to have stopped in 1984.

Negative remarks are:
- the mean speed seems to increase on the rural national highway,
- 42 % of all drivers on the national highway and 50 % of all drivers on the motorway exceed the speed limits.
Literature:
Danish Council of Road Safety Research:

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F. Brodersen, H. Lund og N. O. Jørgensen.

Hans Lund.

Hans Lund.

Færdsselssikkerhedskommissionen:
Delbetænkning om generelle hastighedsgrænser. 1980.
Figure 3: Rural national highway east of Soro.

Mean speeds in km/h.
Figure 4: Rural national highway east of Soro.

Mean values of 6 measurements in km/h.
Figure 5: Rural national highway east of Soro. Percentage of drivers exceeding 80 km/h. Mean values of 6 measurements.
Figure 6: Rural motorway north of Copenhagen.
Mean speeds in km/h for left and right lane.
Figure 7: Rural motorway north of Copenhagen.

Difference between left and right lane in mean speeds in km/h.
Figure 8: Rural motorway north of Copenhagen

Mean speeds and trends 1974-1978.

- Mean 1974-1978, left lane.
- Trend 1974-1978, left lane.
- Mean 1974-1978, right lane.
- Trend 1974-1978, right lane.
Figure 9: Rural motorway north of Copenhagen
Mean speeds and trends 1979-1986.
Figure 10: Rural national highway east of Soro. Percentage of drivers exceeding the actual speed limit. Mean values of 6 measurements.
Figure 11: Rural motorway north of Copenhagen.
Percentage of drivers exceeding the actual speed limit.
Mean values of 5 measurements.
Table 1. Mean speeds 1973-1986 in km/h. Rural national highway east of Sorø, direction west.

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Table 2. Percentage of drivers exceeding 80 km/h 1973-1986. Rural national highway east of Sorø, direction west.

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Table 3. Mean speeds 1973-1986 in km/h. Rural national motorway at Gl. Holte north of Copenhagen, direction north, right lane.

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Table 4. Mean speeds 1973-1986 in km/h. Rural national motorway at Gl. Holte north of Copenhagen, direction north, left lane.

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Table 5. Percentage of drivers exceeding 100 km/h 1973-1986. Rural national motorway at Gl. Holte north of Copenhagen, direction north, right lane.

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"La Gestion de la limitation de la vitesse :
Problèmes et Perspectives"

Par

Yvon CHICH
Directeur de Recherche à l'INRETS
"La gestion de la limitation de la vitesse :
problèmes et perspectives"

Yvon CHICH

I - Situation

En 1986, en France, la diminution du nombre des accidents corporels et celle du nombre des blessés s'est poursuivie (respectivement - 3,4 % et - 4,3 % par rapport à 1985). Mais par contre nous avons constaté une croissance du nombre des tués (+ 4,9 %) qui traduit une remontée de la gravité moyenne des accidents corporels (6 tués pour 100 accidents corporels en 1986, contre 5,5 en 1985); le taux de tués pour 100 Millions de véhicules/km atteint 2,92, en croissance de 1,2 % par rapport à 1985.

Cette aggravation ne paraît pas particulière à la France : en Belgique, en Espagne, aux Pays Bas, en RFA on a déploré un accroissement significatif du nombre des tués, de telle sorte que l'Année Européenne de la Sécurité Routière a été une année de croissance de risque; ce fait qui n'a pas été assez relevé a valeur de signal d'alarme : au-delà de ses aspects conjoncturels il justifie un réexamen des conditions du progrès de la Sécurité Routière.

En effet, on n'a pas assez remarqué que les résultats positifs obtenus dans la période antérieure étaient partiellement dus à des phénomènes indépendants de l'action préventive, facteurs qui peuvent avoir épuisé leur potentiel positif (il en est ainsi en France de l'effondrement du parc des cyclomoteurs qui explique en grande partie la remarquable diminution du nombre des victimes cyclomotoristes, partiellement compensée il est vrai par une croissance du nombre des victimes motocyclistes, ou être susceptibles de retournements péjoratifs pour la sécurité routière (il en est ainsi des fluctuations de l'économie, puisqu'une reprise de la croissance est susceptible d'accroître la mobilité automobile de catégories d'usagers spécialement affectés par un haut niveau de risque, les jeunes conducteurs par exemple)(1).

C'est dans ce contexte de réévaluation de l'action préventive que nous aborderons le problème de la gestion de la limitation généralisée de la vitesse : il s'agit nous semble-t-il d'une question essentielle pour deux raisons complémentaires :

- d'abord parce qu'il ne suffit pas de disposer de mesures réglementaires pour en obtenir le rendement optimal et durable ! N'oublions pas que dès 1972 les rédacteurs de l'OCDE après recensement minutieux de nombreuses études entreprises dans plus de dix pays différents n'hésitaient pas à recourir à l'emploi d'un truisme apparent pour conclure que "lorsqu'une limitation réglementaire des vitesses a pour effet de réduire effectivement les vitesses, on observe une réduction globale du nombre des accidents et des victimes". (2) En fait, le rendement des limitations généralisées de la vitesse est insuffisant, ce qui en d'autres termes plus positifs signifie qu'en ce domaine de véritables gisements de productivité, peut-être les plus importants de toute l'action de sécurité, restent disponibles et largement inexploités.

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ensuite parce que la maîtrise de la vitesse joue comme facteur multiplicateur des autres actions qui portent sur le système route-véhicule-conducteur. Sans nul besoin d'admettre l'appareil théorique de l'homéostasie du risque, et ses excès (3) tous les praticiens de la circulation et de la sécurité routière savent qu'un accroissement des vitesses même discret est contreproductif, dans la mesure même où il diminue ou efface l'apport positif d'une amélioration de l'infrastructure (4). Dès lors la gestion des vitesses devrait être considérée comme la condition nécessaire d'une amélioration de la productivité, en termes de sécurité, des investissements dispendieux consacrés à la route ou à l'automobile.

Or la situation actuelle de la limitation généralisée de la vitesse peut être considérée comme préoccupante : dans divers pays, dont la France, on constate une reprise de la tendance à l'accroissement progressif des vitesses des automobiles mais aussi des poids-lourds. Alors que les limitations de vitesses n'ont eu, dans la dernière décennie, aucun effet significatif sur les économies d'énergie, mais des effets importants en matière de sécurité routière tout se passe comme si l'éloignement de la crise énergétique réactivait les appréciations négatives des limitations de vitesses : c'est un paradoxe cruel que les responsables et chercheurs devraient analyser. Aux États-Unis le Congrès vient de décider l'abandon de la limitation à 55 mp/h et le relèvement des limites à 65 mp/h alors que les plus hautes autorités avaient reconnu après évaluation que l'institution du 55 mp/h était peut-être "la plus importante mesure de sécurité des temps modernes" (5) et alors que les projections prévoient que la nouvelle législation entraînera un accroissement très sensible du risque sur les routes rurales et les liaisons inter-États (6). En Europe, les débats du Parlement Européen et ceux d'un récent conseil des Ministres permettent de constater le désaccord durable quant à l'harmonisation des limitations de vitesses, désaccord qui révèle bien l'importance des intérêts et des enjeux. Parallèlement, nous y reviendrons, nous assistons à une élévation progressive de la puissance et de la vitesse de pointe théorique des produits offerts par l'industrie automobile, de telle sorte que dans un pays comme la France, en l'espace d'environ une décennie, le mode de la distribution des vitesses de pointe des véhicules neufs s'est accru de plusieurs dizaines de kilomètres/heure !

Certes les limitations généralisées de la vitesse sont en vigueur dans la totalité des pays. Néanmoins ces signes que nous avons relevés parmi bien d'autres montrent l'instabilité de la situation et peuvent conduire à se demander si la tendance lourde (le trend) à l'augmentation permanente des vitesses n'a pas repris après une interruption d'une décennie ?

Cette situation ne doit pas surprendre; nous mêmes, à plusieurs reprises nous avons annoncé que la limitation généralisée de la vitesse, acquise parfois après une "dure bataille" (7), était une conquête essentielle, mais une conquête fragile (8)
II - Fragilité de la limitation de la vitesse.

Rappelons brièvement les quatre classes de facteurs qui, isolément et en interaction, expliquent cette fragilité permanente, et "menacent" la limitation généralisée de la vitesse :

1. le conducteur effectue une tâche, la conduite de l'automobile, qui, selon les circonstances, se révèle être très diversément exigente (9). Or il n'est pas niable que le respect strict des limitations de vitesse exige l'accomplissement par l'usager d'un travail supplémentaire, parfois inconfortable et souvent fastidieux, d'autant que cet ajustement doit s'effectuer de manière permanente ce qui, dans l'économie de la décision, est certainement coûteux (10). D'autre part le respect strict de la limitation de vitesse ne peut que contrarier l'attrait de la vitesse qui repose sur une base psychophysiological (recherche de l'activation) et sur une base psychosociale particulièrement manifeste chez les jeunes hommes en phase d'affirmation sociale (11).

La vitesse d'un automobiliste est partiellement sous la dépendance de celle des autres automobilistes : cette dimension irréductiblement collective de la circulation conduit l'automobiliste à remarquer et à surestimer la fréquence et l'amplitude des violations de limitation commises par les autres usagers ; dès lors il suffit qu'une proportion faible d'usagers ne respecte pas, de manière systématique, les limitations de vitesse pour induire progressivement, chez les autres automobilistes, le sentiment de l'inégalité et de l'injustice ; on a d'ailleurs (5) souligné que les Poids Lourds servent de référence, toute dérive de leurs vitesses entrainant une dérive des vitesses des automobilistes.

Enfin, si la sécurité est l'objectif fondamental de la limitation généralisée de la vitesse, il n'est pas indifférent de constater que généralement, aux limites fixées, le conducteur ne perçoit pas directement et physiquement l'augmentation de risque qu'une vitesse plus élevée comporte : pour lui faute des informations recueillies et analysées par le statisticien la limitation, comme "seuil", n'est "renforcée" que par l'action de contrôle des forces de police ou par les hypothétiques manifestations d'une désapprobation sociale.

Les deux logiques, celles de l'usager et celle du spécialiste de sécurité ne peuvent coïncider, en raison même de la nature des informations qui les alimentent.

1. l'évolution technologique marque profondément le système de la circulation routière : outre l'augmentation sensible de la puissance et de la vitesse de pointe qui se perpétue, l'amélioration des qualités dynamiques, celles du freinage et des pneumatiques est une réalité, en particulier dans le haut de gamme ; l'amélioration des suspensions, celle de l'isolation phonique, tout concourt à rendre la conduite rapide plus confortable, et "en apparence" sûre, ce qui représente pour la limitation de vitesse un handicap indiscutable. Parallèlement on a assisté au développement de réseaux routiers conçus pour améliorer la fluidité, la capacité et la performance, réseaux qui visiblement "autorisent" et "justifient" des vitesses plus élevées, le conducteur pouvant ressentir un écart grandissant et finalement frustrant entre la vitesse possible et la vitesse permise. La généralisation de la circulation sur autoroute contribue sans doute à accroître le "besoin" du déplacement rapide et peut induire des élévations de vitesse sur des réseaux dont les caractéristiques structurelles, et donc le niveau de risque objectif, sont très différents. Jusqu'ici, de manière très
générale on doit remarquer que les remarquables potentialités de la technologie ont été utilisées, le plus souvent délibérément, dans le sens d'une offre de vitesse plus élevée.

Le conflit est la forme permanent du débat social sur la limitation généralisée de la vitesse. Alors que la majorité des actions de sécurité routière font l'objet d'un consensus apparent (12) la limitation de vitesse oppose une majorité (de citoyens et même d'automobilistes) appobratrice, à une minorité qui, en paroles et en actes considère que cette réglementation est peu légitime (13,14); les caractéristiques de cette minorité sont bien connues aujourd'hui et sont d'ailleurs assez semblables dans des pays aussi différents que la France (15) ou les Etats-Unis (16) : ce pôle d'opposition est plutôt composé d'hommes, jeunes, conduisant beaucoup et souvent dans un cadre professionnel, acheteurs de véhicules récents, puissants, et pour qui "time is money"; cette population est culturellement, socialement et économiquement mieux armée pour exercer une pression qui prend les multiples formes de l'imposition de modèles, par exemple par la voie de l'action publicitaire. On sait aussi qu'en matière de vitesse structure des attitudes et structure des comportements effectifs sont relativement stables, ce qui autorise une prédiction valide des comportements (17).

Enfin le contrôle du respect de la réglementation est, dans l'état actuel, particulièremenle inefficient, ce qui conduit, notamment les grands rouleurs, à douter de la capacité de la police à surveiller strictement le respect de la réglementation dans ce domaine.

Ce rappel des facteurs qui rendent particulièrement fragile la limitation généralisée de la vitesse pourrait raisonnablement conduire au pessimisme, ou au moins en scepticisme : puisque ces facteurs semblent permanents (en tous cas, au cours de la dernière décennie ils n'ont pas été transformés ni durablement affectés par les variations conjoncturelles, sauf peut-être par la crise de l'énergie ce qui, au regard des enjeux réels, est paradoxal) ne doit-on pas considérer que l'érosion des effets qui affecte toute innovation sociale est inéluctable ? et, le pessimisme faisant le lit de la démobilisation ne doit-on pas en prendre son parti et finalement réduire l'investissement que toute gestion exige ? Trois remarques nous conduisent au contraire à une conclusion inverse :

1) - Si l'érosion des effets d'une mesure de régulation est dans la "nature des choses" encore faut-il relativiser cette érosion; le respect unanime des limitations de vitesse est une pure utopie en raison du caractère de l'obligation et de la complexité des mécanismes qui "produisent" le choix de sa vitesse par le conducteur, hic et nunc. Mais l'effet d'une limitation doit être jugé de façon équitable, par comparaison avec l'absence de limitation ou avec celle d'une limitation fixée à un niveau supérieur : dans ce cas, en dépit des pertes d'efficience générées par l'érosion de la mesure et la croissance du taux des infractions, le plus souvent le bilan global reste positif.
2) - L'importance de l'enjeu est considérable : toute augmentation de la moyenne des vitesses, s'accompagnant de déformations de la forme des distributions des vitesses, induit une très sensible augmentation des accidents, et surtout celle des accidents graves et mortels (18,19); dès lors, à la mesure de cet enjeu, toute gestion de la limitation de vitesse qui permettrait de limiter et de contenir la dérive des vitesses serait très hautement productive.

3) - Enfin la dernière raison qui fonde et justifie notre optimisme relatif, qui n'est au vrai qu'un pessimisme actif, c'est que la gestion de la limitation de vitesse est certainement susceptible d'amélioration et même de mutation : au dispositif classique de contrôle d'une législation doit se substituer une politique permanente, large et ambitieuse, faisant de la maîtrise de la vitesse une priorité manifeste.

III - Voies et conditions d'une véritable gestion de la limitation de vitesse.

Lorsqu'on a pris la mesure de la force et de la permanence des facteurs qui fragilisent la limitation de vitesse ou est obligatoirement conduit à poser le problème de la gestion d'une manière nouvelle qui combine l'indispensable technicité de la connaissance et de l'intervention avec l'activation du débat social qui doit modifier les bases culturelles qui régissent les représentations des acteurs de la circulation. Trois objectifs, qui sont autant de principes d'action, nous paraissent devoir être simultanément poursuivis, chacun gageant les autres :

(1) - ACCROITRE la LEGITIMITE de la maîtrise de la vitesse, et spécialement, celle de la limitation de vitesse.

Si la difficulté de l'entreprise est évidente, elle ne doit pas être accablante :

a) - La première tâche est d'ordre conceptuel et concerne d'abord les praticiens et les théoriciens de la circulation et de la sécurité routière : compte tenu du fait que la vitesse, dans tous les domaines de la technologie et de l'action est considérée comme une Valeur, critère et symbole de l'efficience et de la puissance, la limitation de vitesse apparaît, y compris dans le discours et même la représentation intime des acteurs de la sécurité routière comme un MAL nécessaire, catégorie honorable mais peu valorisante et peu gratifiante. Dans ce domaine les acteurs de la sécurité se laissent enfermer dans la négativité; qui est toujours réductrice de légitimité.

Or, au fur et à mesure de l'accroissement de la complexité et de l'évolution considérable des enjeux de sécurité nous constatons dans tous les grands systèmes industriels (production d'énergie, chimie et bientôt biotechnologies) l'émergence des objectifs de sécurité, corrélative du développement des conceptualisations, de la spécialisation et de la hiérarchisation des compétences. Le temps de la sécurité considérée comme un "supplément d'âme" n'est pas clos, mais il est d'ores et déjà contesté et dépassé.
De même dans la sécurité routière, la compétence, la technicité, l'ampleur des ambitions sont susceptibles de faire peu à peu accéder la sécurité au rang des valeurs positives : il ne s'agit pas d'être les comptables de la mort et du malheur mais les constructeurs rationnels de la sécurité. En peu de mots c'est en réalité une véritable révolution culturelle qui est ici suggérée : elle concerne d'abord les chercheurs et les praticiens de la sécurité qui doivent pleinement assumer les conditions de cette positivité de l'action de sécurité. La maîtrise de la vitesse, dont la limitation de vitesse est un moyen, doit être considérée comme une condition centrale de la construction de la sécurité d'un système de circulation routière. La légitimité de la limitation de vitesse passe d'abord par une véritable théorie de l'action de sécurité qui reste aujourd'hui segmentaire et par conséquent mal protégée de la contestation et du scepticisme.

b) - Les ressorts de la légitimité ne sont pas seulement d'ordre intellectuel, mais aussi d'ordre social. C'est pourquoi il faut assurer le fondement démocratique d'une entreprise de régulation et de prévention en organisant et en favorisant le débat et l'expression des conflits. Rien de plus nocif et de plus trompeur que le prétendu consensus en matière de sécurité routière (12). En réalité l'analyse ap- profondie des représentations sociales de l'accident et de l'action de sécurité (13) révèle que la limitation de la vitesse divise l'opinion d'une manière profonde et durable : d'un côté une majorité qui reconnaît dans la limitation de vitesse une nécessité essentielle du système de la circulation, de l'autre une minorité contestataire qui n'admet pas le bien fondé de cette réglementation et qui, sous diverses formes, prétend s'en affranchir ; or cette minorité que les constructeurs automobiles et les publicitaires connaissent bien et utilisent c'est majoritairement celle des "grands usagers" de l'automobile et de la route : hommes, jeunes et dans la force de l'âge, actifs, grands roueurs, acheteurs de véhicules neufs, puissants, nerveux, intéressés par la technique et ses développements, affirmant leur "différence", leur "capacité" et leur "maîtrise". Laisser libre cours aux discours, bien relayés par la publicité, la presse spécialisée, le cinéma d'action,... de cette minorité c'est à l'évidence miner la légitimité de la limitation de vitesse qui va devenir frein, brimade et manifestation d'une attitude ridicule et frileuse. C'est pourquoi le débat et le conflit doivent être recherchés et d'abord par la communication d'une information précise aujourd'hui trop peu disponible : il faut afficher le coût d'insécurité de la vitesse, y compris le coût différentiel selon la marque et le type du véhicule, insécurité pour soi et pour autrui, ou insécurité interne de l'occupant du véhicule et insécurité externe subie par les "adversaires" très inégalement protégés (piétons, utilisateurs de deux roues, automobilistes différenciés selon la masse de leur véhicule, utilisateurs de poids lourds) (20); il faut aussi préciser et diffuser l'ampleur des effets des limitations de vitesses "réussies", ce que l'on fait très peu et très mal, comme si curieusement, la conviction manquait. Puisque la limitation de vitesse est l'objet d'un conflit latent on ne doit nullement craindre les effets d'un conflit manifeste ; au contraire il importe que les individus, les groupes, les associations, les institutions intéressées à la sécurité manifestent leur prise en charge du problème de la légitimité sociale de la limitation de vitesse : l'enjeu, à terme, c'est celui d'un déplacement des attitudes par la diminution de la légitimité...
"technique" des grands usagers de la route et l'accroissement de la légitimité, non seulement morale, mais aussi scientifique et technique des constructeurs de la sécurité. Car la légitimité sociale génère sous des formes multiples un contrôle social entre pairs qui est la véritable condition d'une première intériorisation de la loi.

(2) - Intégrer la limitation de vitesse dans l'ensemble des moyens de la MAÎTRISE de la VITESSE. Il importe en effet de bien tirer toutes les conséquences du fait que le choix de la vitesse s'analyse en grande partie comme la réponse de l'opérateur, le conducteur, à une situation saisie dans sa dynamique; proposer perpétuellement des classes de situations qui accentuent l'écart entre la vitesse "possible" et la vitesse limite, c'est à coup sûr placer le conducteur dans une position difficile et c'est à terme diminuer de manière certaine l'effet attendu de la limitation de la vitesse. Il convient donc de développer une véritable ergonomie de la limitation de vitesse dont l'ambition est de réduire l'abstraction de la réglementation en offrant au conducteur des situations qui "induisent" le choix d'une vitesse compatible avec la limitation; il s'agit en somme, en termes de gestion, de considérer la vitesse comme variable dépendante ou résultante, et pas comme une variable indépendante qu'elle n'est pas (a). Cette ergonomie de la vitesse dont seuls les rudiments sont aujourd'hui disponibles peut utiliser trois moyens complémentaires:

- le tracé routier, et plus généralement la conception globale de la route, doivent être adaptés à la limitation de vitesse, le principe de base de toute orientation ergonomique résidant dans l'adaptation de la tâche à l'homme et non l'inverse. Certes le traitement ergonomique peut se révéler très difficile à concevoir et à mettre en œuvre, notamment en rase campagne; mais à partir du moment où la conception de la route intègre une véritable dynamique de la conduite les principes fondamentaux de rythmicité, de réduction de l'incertitude, de gestion des transitions assurant une homogénéité modulée permettent de proposer des solutions efficaces; d'ores et déjà le traitement des points singuliers, celui des intersections, des voies d'insertion, des giratoires permet d'intégrer la vitesse comme variable résultante (21).

- l'équipement de la route, la signalisation statique et dynamique est un moyen puissant de régulation de la vitesse lorsqu'il est utilisé en synergie avec les caractéristiques routières et en fonction des caractéristiques du trafic (22).

- enfin l'ergonomie de la vitesse, et spécialement celle de la limitation de vitesse est susceptible de générer dans les futurs automobiles divers systèmes de régulation et d'aide à la conduite qui doivent être développés à partir d'une analyse objective des difficultés rencontrées par les conducteurs (23). Sans s'en étonner on remarquera le faible investissement consenti par l'industrie de l'automobile dans l'ergonomie de la maîtrise de la vitesse; or toute gestion de la limitation de vitesse exige qu'un effort sérieux soit lancé et poursuivi, en spécifiant les classes de situations-problèmes et en validant en vraie grandeur les solutions proposées, dont certaines hélas peuvent être de simples gadgets, ou même comporter des effets pervers inattendus. C'est d'ailleurs l'occasion de faire remarquer l'ambiguïté dangereuse de certains grands projets qui se proposent d'utiliser les potentialités de l'électronique pour produire des voitures "intelligentes" (24) : chez certains des promoteurs de ce développement technologique l'espoir de permettre ainsi une augmentation sensible des performances, et notamment de la vitesse, est
manifeste; cette illusion techniciste est une nouvelle menace pour la sécurité routière et spécialement pour la limitation de vitesse. Au contraire il importe de réunir les conditions de développement d'une technologie de la maîtrise de la vitesse permise par les progrès de l'électronique, et sur laquelle nous reviendrons plus avant.

(b) - L'exploitation de la route est nécessairement appelée à des développements importants induits par l'augmentation de la circulation et les limites physiques et économiques des grands investissements routiers. Nous assistons progressivement à l'émergence d'un nouveau métier, celui d'exploitant ou de gestionnaire de la route et de la circulation : de même qu'il ne suffit pas de construire des voies ferrées et des locomotives pour disposer d'un système performant de circulation et de transport, de même, toutes proportions gardées et spécificités reconnues, il ne suffira plus d'offrir des routes et de vendre des automobiles pour en être quitte avec la circulation automobile. Ce que nous proposons c'est que la limitation de vitesse, parce qu'elle aura été pleinement reconnue comme essentielle (voir plus haut) soit partie intégrante des objectifs et des responsabilités des gestionnaires de la route et de la circulation. Beaucoup plus qu'aujourd'hui la vitesse doit être pleinement intégrée à la gestion, ce qui exige qu'elle soit réellement connue, analysée, modélisée, de telle sorte qu'elle accède progressivement au rang de variable de sortie, variable résultante, véritable caractéristique d'un produit. Bien entendu ces nouveaux gestionnaires de la circulation devront disposer de concepts, de méthodes et de mesures qui exigent un développement technologique de la saisie et du traitement des informations de vitesse.

A notre sens cet accès à une nouvelle perspective, celle de la gestion intégrée et de la direction par objectif est certainement un élément d'innovation essentiel qui doit s'imposer dans la perspective de la construction rationnelle de la sécurité et de la qualité de service : la limitation de vitesse y trouvera une nouvelle signification et un nouveau statut.

(3) - Accroître la cohérence et la crédibilité de la limitation de vitesse.

Nous avons indiqué plus haut la nécessité d'une plus grande légitimité de la limitation de vitesse. Mais une régulation normative ne doit pas être menacée par l'incohérence, apparente ou réelle, et doit être renforcée d'une manière probante.

(a) - Il faut donc d'abord prendre la mesure d'une situation que nous qualifierons de schizophrénique : dans le temps même où nos sociétés ont, à contre cœur le plus souvent, reconnu la nécessité de la limitation de vitesse elles ont aussi, par le canal de l'industrie automobile, produit et offert des engins de plus en plus puissants capables de performances sans aucune commune mesure avec les niveaux les plus élevés des limitations de vitesse. Et cette offre, qui d'ores et déjà a profondément modifié la structure du parc des véhicules en circulation, a vu son impact majoré et amplifié par l'orientation publicitaire de célébration de la puissance, de la vitesse et de l'agressivité. Schizophrénie, le mot n'est pas trop fort, dont les effets individuels et sociaux mériteraient une évaluation sérieuse. A tout le moins cette forme éclatante, et même provocante, de l'incohérence, inscrit la limitation de vitesse dans le registre de l'impuissance, et le respect de cette limitation dans celui de la plaisanterie. - Certes, en vertu de
de l'adage du client roi, "le client a toujours raison", certains prétendent que c'est la demande qui importe, l'offre de l'industrie étant seconde... En réalité l'offre, si elle répond à une demande ne fait que l'amplifier et surtout elle lui confère une légitimité "sérieuse", celle des producteurs, des techniciens; celle de l'argent et de la différenciation sociale. Quelque soient les raisons qui conduisent à cette situation (retombées inattendues de l'effort de recherche consacrée à la motorisation, politique de marketing orientée par la recherche des marges les plus confortables, concurrence plus ou moins faussée par l'hétérogénéité des législations...) il est important de la placer au coeur de notre interrogation sur la gestion de la limitation de vitesse : tout progrès passe par une réduction de cette incohérence; il appartient à tous les acteurs intéressés de proposer les voies de l'action capable de réduire une dérive nuisible à la sécurité, c'est à dire à l'intérêt général : l'autonomie technologique et mercantile doit elle rester sans limites et sans contreparties ?

(b) - L'amélioration de la crédibilité de l'action normative passe par une croissance tangible du rendement du système de contrôle et de sanction; certes le calcul des probabilités montre que rapportée à l'unité élémentaire (l'infraction hic et nunc), la probabilité de détection ne peut qu'être faible, sauf à modifier complètement les conditions du contrôle. Il y a là une difficulté objective qui rend indispensable l'élaboration d'une stratégie d'action fondée sur la recherche de l'optimum, compte tenu des moyens, des enjeux et des caractéristiques des infractions à la vitesse; mentionnons quelques unes des pistes de cette stratégie :

- le progrès de la technologie doit se manifester sous deux aspects complémentaires : d'une part, comme il a été dit plus haut, les aides à la conduite doivent effectivement assister le conducteur dans sa tâche de respect de la limitation de vitesse puisque certaines infractions s'analysent comme des dérives et des erreurs et les aides à la régulation doivent, chaque fois que le paramètre sera utile et pertinent comporter une prise en compte de la limitation de vitesse (signalisation dynamique interactive par exemple)(22).

- d'autre part les techniques de détection et d'enregistrement de l'infraction sont susceptibles d'être améliorées et diversifiées, qu'il s'agisse de la précision et de la fiabilité, de la facilité d'emploi et de mise en oeuvre, de la fréquence et de la discrétion. Dans certains cas l'enregistrement, partiellement effacable ou non, ne saurait être écarté sans examen attentif des finalités : tous les systèmes de transports évolués comportant ces modalités d'enregistrement, outils de gestion, d'enquête et de recherche : pourquoi, sauf à relativiser les enjeux de la sécurité routière, la route ferait-elle exception ?

- les comportements d'infraction à la limitation de vitesse ne sont pas répartis de manière aléatoire; en effet, si tous les usagers de la route sont susceptibles de commettre une infraction à la vitesse on constate des régularités qui permettent de caractériser des "groupes à risque" : diverses études montrent l'existence d'une remarquable stabilité des comportements dans ce domaine, qui fait d'une infraction constatée un bon prédicteur d'infractions antérieures et postérieures (17) et qui justifie d'ailleurs le concept de "comportement de base" (25). En conséquence la gestion du contrôle ou de ses suites peut en être singulièrement facilitée, à condition d'élargir, de manière sélective, la gamme des moyens mis en oeuvre.
- la sanction proprement dite, conséquence de l'infraction détectée est évidemment un élément constitutif de la crédibilité du système. Faute d'un bilan de l'efficacité de la sanction et de ses caractéristiques on retiendra quelques principes soumis à évaluation : productivité du barème, en fonction de l'ampleur de l'infraction d'une part, du caractère de récidive d'autre part; recours à l'amende considérée comme le moyen de base; recours à une échelle graduée de restrictions de conduite; prise en compte des infractions pour le calcul du bonus/malus de l'assurance automobile.

- en matière de vitesse les "déviant" caractérisées ont en général construit un système d'attitudes et d'opinions très affirmé et peu sensible à la simple remontrance normative que comporte la sanction. C'est pourquoi il convient de réfléchir aux moyens d'ébranler la légitimité de l'infraction : on peut recourir à l'information qui doit être une énonciation rigoureuse des faits habituellement ignorés ou scotomisés (la relation étroite entre vitesse et insécurité); mais aussi à l'activation de processus de relations inter-personnelles, dans l'esprit des groupements "d'alcooliques anonymes" : il faut traiter l'infraction à la vitesse pour ce qu'elle est, une maladie de l'adaptation sociale et de la reconnaissance d'autrui.

Ces principes constitutifs d'une stratégie d'action doivent être mis en œuvre par de véritables gestionnaires; ce que nous avons dit de l'exploitation de la route est valable dans ce domaine du fonctionnement du système de contrôle et de sanction, mais l'application des principes d'une gestion par objectifs est ici directement soumise aux spécificités, et en l'espèce, à l'universalité du droit et de la justice. Néanmoins l'amélioration du rendement du système est une nécessité qui justifie une approche pluridimensionnelle (26). Reste le problème du sous-système qui lie, parmi d'autres variables, le seuil nominal de l'infraction, la tolérance de fait, la proportion des infractionnistes : contentons-nous de répéter ici que même un taux élevé d'infractionnistes n'invalidé pas obligatoirement une réglementation dont les effets généraux, comparés à l'absence de réglementation ou à une limitation à un seuil plus élevé, restent positifs; néanmoins un taux élevé d'infractionnistes atteint la légitimité sociale de la norme qui à terme se trouve menacée : le récent relèvement des limitations américaines, dont le coût d'insécurité est inéluctable, illustre ce processus de perte de crédibilité et de légitimité.

CONCLUSION :

Il est aujourd'hui temps de comprendre que la limitation de vitesse ne doit pas être le placage provisoire et empirique de l'abstraction réglementaire sur la réalité multiforme et évolutive de la circulation; ce sont les caractéristiques fondamentales du système de la circulation routière qui sont déterminantes : système ouvert de déplacement de masse d'unités quasi-autonomes, libres de leur départ, de leur trajet, de leur itinéraire; système où la valeur centrale est celle de la liberté et de la souplesse, ce qui implique une grande variabilité des états, des situations et des acteurs. Dans l'économie d'un tel système la limitation de vitesse est une règle a minima qui conditionne le fonctionnement optimal. Il est regrettable que, même chez les bons
esprits, la limitation de vitesse n'ait pas été perçue pour ce qu'elle sera de plus en plus, un signe d'accès au fonctionnement adulte; mais il est vrai qu'en matière automobile, comme ailleurs, le dépassement du stade infantile reste pénible et coûteux, et toujours à merci d'un "coup" de nostalgie.
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SOCIAL, ECONOMIC AND INSTITUTIONAL IMPEDIMENTS TO THE HARMONIZATION OF VEHICLE SAFETY STANDARDS

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Traffic safety in Canada has benefited from the experiences of many countries, e.g. seat belt legislation from Australia, drinking-driving laws from the U.K., and motor vehicle safety standards from the United States, by adapting these laws and practices to meet the needs of Canadians. Since the traffic milieu in Canada is most similar to that in the U.S with similar vehicles, roads and driving conditions, it is not surprising that Canadian road safety countermeasures are also similar to those in the U.S.

Notwithstanding the similarities between the two countries, there are differences, for example in the mix of vehicles and road types (multilane vs two lane) and safety measures which affect Canadian decisions on motor vehicle safety standards. The Canada-U.S. Automotive Trade Agreement and the resultant integrated North American motor vehicle industry have made the harmonization of vehicle safety standards a high priority. With almost 30% of the vehicles sold in Canada being manufactured outside of North America, an effort is also made to ensure compatibility between Canadian and non-North American vehicle safety standards.

This paper describes how Canadian social values and institutions, political framework, economic policies and safety countermeasures currently in place, affect motor vehicle safety standard decisions. The Canadian Parliament, by enacting motor vehicle safety legislation in 1970 and successive governments through their decisions and directives, have established the criteria and policies which guide the development and adoption of safety standards. The existing driver, road and vehicles-in-use safety countermeasures in Canada which have been implemented by each of the Provincial governments according to their needs and preference, have a direct effect on the potential benefits that can be expected from proposed vehicle standards.

The manner in which these factors affect Canadian efforts to further motor vehicle safety standard harmonization are described; examples from the development of occupant protection, daytime running light, bumper and headlight standards are used to illustrate the problems identified. Some of the factors and decisions described may be unique to Canada, however, most will be similar to those experienced by other smaller countries making independent safety decisions.
SOCIAL, ECONOMIC AND INSTITUTIONAL
IMPEDIMENTS
TO THE HARMONIZATION OF VEHICLE SAFETY
STANDARDS

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Since the early days of government vehicle safety standards in Canada, following proclamation of the Motor Vehicle Safety Act, January 1, 1971, harmonization of Canadian safety standards with those in the United States and Europe has been a stated objective. The original regulations and vehicle safety standards were very similar to those in place in the United States and, for the most part, reflected best engineering practices in the automotive industry. In a few areas, most notably lighting, the Economic Commission for Europe (ECE) standards were identified as acceptable alternatives.

This paper accepts the premise that the international harmonization of motor vehicle standards is a desirable objective and that economic benefits will result from harmonization. However, it does not accept that this is more important than the original objective of establishing standards, that of saving lives, reducing injuries and, in the case of emission standards, improving air quality. Before it will be possible to identify ways to improve harmonization the reasons for non-harmonization need to be better understood.

Proponents of harmonization often point to the similarities of traffic and vehicle performance which should facilitate the harmonization of vehicle design and performance standards. Even though this may be true, significant differences do exist. Variations in the traffic accident fatality rates among countries and in the character of these rates demonstrate that these differences are real. For example, international accident statistics show that Canada has the highest proportion of vehicle occupant victims to non-occupant victims of all ECMT countries, while also having one of the lower fatality rates based on deaths per unit of travel; pedestrians and bicycles are involved in a much larger percentage of fatal accidents in Europe that in North America and Australia.
These variations in accident experience should not be surprising since there are differences in the mix of road types and vehicles, traffic operations practices, rules of the road, law enforcement practices and safety programmes between countries. While there may be a lessening of these differences they still exist and will continue to exist into the foreseeable future.

Dr. Carl Hahn, Chairman of the Board of Management, Volkswagen A.G., in an article in the International Journal of Vehicle Design states: "Sophisticated drivers today are very much the same around the world, regardless of their homeland. Their preferences in automobiles also became more and more similar, offering us an excellent opportunity to attack the proliferation of regulations ...", and yet, even with this similarity in preferences, over 500 models of passenger vehicles find buyers in Canada.

It is possible to group some of the more critical factors that explain these differences among countries into social, economic and institutional categories.

**SOCIAL**

Although motor vehicle safety standards are technical in nature and their benefits are frequently described in economic terms, they are the product of social legislation. The social norms of each country are different and have produced a unique set of social legislation for each country. The legislation establishing motor vehicle safety standards is surprisingly similar in all countries. Other laws regarding road use (e.g. speed limits, right-of-way control), drivers (e.g. drinking and driving, seat belt use) and vehicles-in-use (e.g. vehicle inspection, winter tires) are quite different.

In Canada, laws regarding roads, drivers and vehicles-in-use are within the jurisdiction of each of the ten provinces. While there is close co-operation among the provinces there are some significant

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differences in the traffic laws, (e.g. studded tires are banned only in Ontario and right turns on red lights are permitted in all provinces except Québec). All ten provinces now require vehicle occupants to use seat belts. The first such law came into effect in 1976, the last in 1987. Australia had such laws in every state in the early 1970’s and the United States still does not have mandatory use laws in every state.

This variation in safety laws affects the role of vehicle safety standards in national road safety strategies. In Canada, where seat belt laws are widely accepted, vehicle safety standards are required to ensure that effective seat belts are available in every vehicle. Injuries to vehicle occupants using seat belts are different than those to unbelted occupants. Priorities for seat belt standards in Canada must address head rotation, facial injuries, and abdominal injuries. Where seat belt use is very low, priority must be given to increasing seat belt use. In the United States, this has lead to standards that increase comfort and convenience, perhaps to the detriment of effectiveness, and to standards for passive restraints such as automatic seat belts and air bags. While air bags may reduce facial injuries when seat belts are also worn; automatic seat belts do not appear to offer any safety advantages to seat belt wearers.

It is difficult to see how harmonization of occupant protection standards can be achieved as long as these differences in seat belt use exist.

The willingness of citizens to give up some freedoms (to speed, not wear seats belts, etc.) varies among countries and not only affects the mix of safety laws, but also the type of vehicle safety standards that are acceptable.

**ECONOMIC**

Two steps required in the Canadian regulatory process are an examination of all alternatives to the regulation and an evaluation of the social and economic costs to ensure that benefits exceed costs. The possible alternatives and the potential benefits and costs will vary from country to country. Harmonization itself will be one of the benefits and non-harmonization one of the costs.
The Canada/U.S. automotive trade agreement has resulted in an integrated industry in North America. Eighty percent of the vehicles manufactured in Canada are exported and over 70 percent of vehicles sold in Canada are imported. Unique Canadian standards, therefore, result in a significant cost and added complication to the manufacturer which must be considered when such a standard is proposed. The cost, including development costs, of equipping 10 percent of the North American fleet to meet a Canadian requirement will be much greater, on a per vehicle basis, than for 90 percent of the fleet to meet a United States requirement. In fact, there may be a cost to deleting a U.S. requirement from the Canadian portion of the fleet should Canadian standards effectively prohibit the U.S. feature.

On the benefit side, each country has a different safety milieu which will affect the potential benefits. Perhaps the best example of this are the restraint standards. In a country with high seat belt use, improvements resulting in more effective seat belts will provide much greater benefits than in a country with low wearing rates. Where use rates are low and where seat belt use laws and/or public education are found to be ineffective or unacceptable, passive restraints may well be a very attractive, cost-effective alternative.

In analyzing the costs and benefits of an automatic daytime running light (DRL) standard in Canada, a number of factors were considered. Experience with the practice of running with low beam headlights on has proven to be an effective safety countermeasure in the Nordic Countries, although only Norway has a vehicle standard that requires new vehicles to be equipped with an automatic DRL system. One of the difficulties in forecasting the benefits of a DRL standard for Canada was estimating the transferability of Nordic experience to Canada and in expanding the results of relatively small fleet studies to the whole Canadian fleet. The cost of a DRL system, either one that turns on low beam headlights automatically, or (the preferred system) one that activates reduced intensity forward lights has been estimated to be as low as 15-20 Canadian dollars. In determining the cost of the standard, the savings that would accrue to those who currently voluntarily turn on all their vehicle lights as a DRL (from reduced fuel use and bulb burnout that would result from an
automated reduced intensity system) were also considered.

The form of economic analysis that is recommended identifies measurable economic benefits (lost time and productivity, medical costs, vehicle and property damage, etc.) and costs, leaving the final assessment of the social benefits of saving lives and reducing suffering and costs such as lost freedoms, to the political system. In this manner, cost/benefit analysis is only one more tool to assist the political decision maker.

INSTITUTIONAL

In passing the Canadian Motor Vehicle Safety Act and establishing the authority for motor vehicle safety standards, the government assumed the responsibility — rather than the auto industry — for determining safety policy. The industry and the public, through national safety organizations, have established mechanisms for providing government with their views on the development of such policy. The Motor Vehicle Safety Act includes a clause (section 9) which requires pre-publication of regulations or amendments to regulations and that "a reasonable opportunity shall be afforded ...."to make representations to the Minister.

In recent years in North America there has been concern that there is too much regulation and that governments must reduce the number of regulations and their adverse economic impact. While this concern has been expressed primarily about economic regulation, safety regulations have come under much closer scrutiny as well. One of the results of this has been much greater involvement of the politicians in the process.

In Canada, the government has established a federal regulatory policy which is summarized in ten guiding principles. These principles have lead to a Citizen's Code of Regulatory Fairness. Included in the guiding principles are references to the need to: ensure benefits exceed costs; regulate fully under the control of elected government representatives; increase public access and participation; improve and even intensify regulation where public protection requires it; and limit the rate of growth and proliferation of new regulation.
At the current time the sequence of events which lead to a new vehicle safety regulation are:

a) identification of candidate safety standards, from research, the public, safety organizations or foreign standards;

b) examination of the technical and economic feasibility of the regulation and identification of non-regulatory alternatives;

c) preliminary discussion with the interested parties regarding the potential impact of a vehicle safety standard;

d) (when warranted following steps a, b, and c) pre-publication of a proposed standard, including an analysis of the social and economic impact of adopting the standard, for comment from interested parties (public hearings are also possible at this stage);

e) examination of formal comments and reconsideration of the original proposal in light of comments received; and

(if significant changes in the original proposal are being proposed, steps d and e are repeated)

f) publication of the new regulation.

It should be noted that the Minister approves of each step in the process from d through f.

Harmonization and the direct costs associated with non-harmonization are considered in the analysis of economic impacts.

In the process described, regulation-making is intended to be a very transparent process which ensures that all factors are examined and a balanced decision is possible. Events in other countries affect the economic analysis but do not play a major role in the final decision. Once the process begins in Canada, it will continue unless evidence is produced to show that Canadians will not benefit sufficiently to justify the costs, regardless of decisions in other countries brought about through their political process or their courts.
Even if, in the interest of harmonization, similar regulations are proposed simultaneously in two or more countries, there is no guarantee that the final regulation will be adopted in the same form after the national economic and social factors are considered and after it undergoes public examination. To overcome this problem, the introduction of new standards could be delayed until after the regulatory process is complete in the originating country, however, if the safety standard offers obvious safety benefits such a delay is not acceptable.

CONCLUSIONS

The Motor Vehicle Safety Act of 1970 was passed by Parliament because Canadians wanted their government to determine vehicle safety policy, recognizing that this was not possible in the Canadian market-place. Canadian safety standards should provide benefits to Canadians that clearly exceed the costs. Harmonized standards, in that they should be more economical and less disruptive to industry, are consistent with the other objectives of the vehicle safety programme. Nevertheless harmonization will always be a secondary goal to that of saving lives and reducing injuries in Canada.

Harmonization is favoured by all governments in the automobile producing countries. Given this support there are opportunities to improve harmonization.

AVENUES FOR HARMONIZATION

Harmonization can be facilitated by the use of performance standards rather than design restrictive standards. Improvements in the measurement criteria and test methods are required before performance standards can replace all design standards. This approach will give the manufacturers greater flexibility to design and build vehicles that meet somewhat different national standards.

A careful examination of the impact on safety of the differences between standards would probably reveal that there are many cases where the safety consequences would be slight, if even measurable. In these instances changes in rules would be possible. In some cases, international studies might be needed to determine if variances in safety standards produce significant variances in safety. Major vehicle producers are already familiar with the differences in standards and together with national governments they could document these differences and their safety and economic impacts.
While some progress has been made in both these areas, advances could be faster. Government and industry working together could accelerate the process. There is evidence in Europe, North America, Japan, Australia and elsewhere that national governments are aware of the value of greater harmonization and are prepared to work towards this objective.

REFERENCES


INTERNATIONAL CONFERENCE ROADS AND TRAFFIC SAFETY
ON TWO CONTINENTS

Gothenburg, 9-11 September, 1987

USING COMPUTER GRAPHICS TO COMPARE US AND EUROPEAN
BEAM PATTERNS

ABSTRACT:

Eugene Farber, Ford Motor Co.

This presentation uses computer graphics to compare US and
European beam patterns. The computer graphics images are
generated by a computer program called IVIEW. These images depict
a driver's-eye-view of a roadway at night. The IVIEW system provides
the capability of varying many aspects of the scene, including the
presence or absence of glare from an opposing vehicle, road geometry
(hills and curves) lane configuration, lane lines in their various
configurations, the number, size and location of pedestrians and road
signs, and the reflectance of these elements and of the road surface
itself.

The IVIEW images in this presentation compare European and US
beam patterns under different geometric conditions. Each slide shows
the same scene lit by the US lamp and by the European lamp. There
are two such slides for each scene: one with no glare and one with
glare from an opposing vehicle at 300 feet (about 90 meters). In all of
these pictures, the glare lamps are the same as the "observer's"
lamps. The scenes differ in roadway geometry and in the presence or
absence of glare from an opposing vehicle. The geometric conditions
modeled include a straight road, horizontal and vertical curves (hill
crests and valleys) of varying direction and degree of curvature, and
combined horizontal and vertical curves. Each scene includes eight
pedestrian "targets" and two flat, vertical surfaces representing road
signs.

Disability glare (the aspect of glare that interferes with vision) is
modeled in these pictures using the Fry glare equation. The veiling
haze at each point in the picture is a luminance calculated by the Fry
equation for a driver looking at that point in the scene.

In general, the pictures demonstrate the following:

- On straight roads, the US lamps provide better visibility of
  pedestrians on both sides of the road and of road signs,
  especially overhead signs, and of the left road edge. This is true
  with or without glare.

- On straight roads, the European beam produces substantially
  less glare than the US beam. In actual driving, European lamps
  are usually felt to produce less discomfort but, as noted above,
  the visibility levels are still better with the US beams in
  meeting situations.
- On curved and/or hilly roads, different elements of the scene may be better illuminated by one lamp or the other, depending on the details of the road geometry.

- There are two situations in which the European beam, with its sharp cut-off appears to perform poorly compared with the US beam. These are (1) left hand turns of about 4 or 5 degrees of curvature (or greater): the European beam produces very high glare levels; and (2) sag vertical curves (i.e., valleys): with the European beam, visibility is sharply curtailed beyond 30-40 meters.

Vehicle Performance, Sept. 10.
CCS
COMPUTER CONTROL SUSPENSION
- the technique

by Lars Runo Tillback, Volvo Car Corp, Sweden

Four hydraulic cylinders (1 and 10) and a computer (12) - these are the main components of the suspension system which is Volvo's latest research project in the field of safety.

The technique which unites properties such as sportiness and comfort in one and the same suspension system works like this.

CCS, Computer Control Suspension, is a microprocessor - controlled suspension system. Springs, stabilisers and shock absorbers have been replaced by four hydraulic cylinders (1 and 10) - one at each wheel. The hydraulic system is based on an oil pump (4) which creates the pressure and servo valves (13) which regulate the cylinders.

Computer control

The heart of the CCS system is a computer (12) located in the boot. It receives information on the various forces which affect the movement of the wheels and the actual car. This information is transmitted by sensors located in the hydraulic cylinders, the electronic speedometer, the steering gear (5) and inside the car (7 and 9).

The computer processes the information and then uses it to regulate the valves which control the oil pressure in each cylinder. There is an accumulator (2) at each wheel and it creates pressure in the event of sudden wheel movements.

Registered on tape

When the results have been processed in a special computer system the CCS computer can be programmed with optional information relating to the softness or hardness of the suspension, the degree to which the car should be allowed to roll or the stiffness of the damping forces. A total of 66 variables can be programmed independently. This is done using two mini-computers; one (3) is integrated in the dashboard, while the other is portable. Both are connected to the main computer in the boot.

New chassis in just one minute

Instead of building a whole range of cars with different suspension systems, CCS allows the design engineers to "change the chassis" on a car in less than one minute. 12 different "chassis" can be stored on a mini-cassette which fits the portable computer.
Det.
1. Front actuator
2. Accumulator
3. Control panel
4. Hydraulic pump
5. Steerangle transducer
6. Oiltank
7. Yaw gyro
8. Long. lat. accelerometer
9. Rear actuator
10. Hub accelerometer
11. Computer unit
12. Servovalve

--- Hydraulic pipe
--- Transducer signal
--- Control signal
A TIRE MODEL FOR ALL SIMULATED CAR-DRIVER SITUATIONS

by Friedrich Böhm, Professor Dr. techn, 1. Institut für Mechanik
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ABSTRACT

A short overview shows the evolution from the beginning of tire modelling
to complex tire models for the computation of non steady state tire
behaviour. Using transport theory and the modal forms of the tire belt, it
is possible to calculate the contact forces in all cases of car movement,
even the start or fully stop of a car.

The influence of the friction function and its corresponds to the stability
of the model is shown in some examples. The modelling of the tire belt as
a rigid body is sufficient as long as no high frequency excitation occurs. If
there is an obstacle, the high frequency oscillation of the elastic belt is
taken into account.

Some examples of car-dynamics with a driver model (open or closed loop)
are shown finally. The model has up to 30 degrees of freedom. Different
tire models can be used, by means of the calculation time, a simplified
model with a second order differential equation is chosen in several cases.
Some of the results are shown by animation.
Survey

The paper reports on a tire model which is elucidated from mechanics of non stationary rolling contact. The inertia forces of the tire structure are used to integrate high frequency rolling behavior. In case of low frequency rolling the model uses only second order kinematic theory and saves computing time. The influence with sliding friction between tire and road on tire characteristics is shown. The model is also used to simulate car-driver behaviour.

1. Introduction

Historically the beginning of the dynamics of cars is the non-holonomic constrained defined by Hertz, 1894. Because of difficulties to stabilize wheels which are steerable Schlippe and Dietrich /1/ extended the theory of rolling contact of only a single contact point to a contact of an elastic line for the equivalence of the contact patch of an elastic tire. Regarding the transport of weak disturbances through the contact patch they introduced a linear partial differential equation for this rolling contact. While they changed to an integral equation Johnson, Pacejka and Sperling /2/ solved the problem by assistance of transport equations for longitudinal and lateral deformation of contact patch. The model describes onset of flutter very well, but only non-sliding contact points can be computed, and more important, only constant vertical tire forces can be taken into account.

On the other hand to simplify the computation Riekert /3/ introduced 1942 the "effective slipping angle" of the contact patch which is caused by the relative lateral velocity of the contact patch to the ground. Using this by Riekert new introduced term Boehm, Mitschke and others /4/ computed the non-linear friction of in-stationary sliding contact for long wave length of disturbances. This leads to a non-linear, implizit differential equation and for rolling velocity equal to cero, this equation becomes singular. It is impossible to start the integration of car movement with velocity equal to cero or to stop the car to rest. It is also impossible to compute short wave length disturbances, as for instance tire nonuniformities,
To overcome this difficulties Boehm /4/ introduced a new algorithm for the kinematics of rolling contact to compute deformations and sliding at several points of the contact patch simultaneously. This leads to a theory of the transport of strong disturbances through the contact patch. Also it is now possible to take into account the in time variable area of contact.

Difficulties exist in that the changing from stick to slip can be numerically stabilised only by introducing the inertia forces of the tire. The contact algorithm has two parts, firstly the new generated contact area is computed, which is born in one time increment $\Delta t$ and secondly old contact points, which are in persistent contact are transformed by a transformation consisting of rotation and translation in plane of road.

The vertical force in the contact area is computed for each time increment during numerical time integration of the differential equation of the belt modeled as an elastic circular ring on elastic foundation. For computing time reasons this vertical forces are computed by finite difference method of the mechanical model for belted tire by Boehm /5/ and only few degrees of freedom are used there. This model gives good results for statically deflections also if lateral or longitudinal forces are applied. Measurements by Heckl /6/ have shown that the vertical acceleration of contact points during rolling is very small and contact points are nearly at rest. Therefore Schulze /7/ used a rigid ring model and connected it with the horizontal tire dynamics.

This model was recently improved by Schulze /8/ using the integration method of Gear and so it is possible to integrate stiff differential equations of the belt by the same time increments which are used for the contact algorithm of the kinematic transport algorithm. Now it is possible to simulate the rolling over road irregularities and to connect vertical dynamics of the tire with horizontal dynamics, see figure 1.

![Figure 1](VTI RAPPORT 332 A)
2. A dynamic tire model with several contact lines for the belted tire

Computing of static deflections by finite element methods Rothert, Tang /9/ and also by methods of Boehm and Wilmerdings /10/ is very time consuming and it is therefore not possible to connect this computations with the rolling tire equations. To improve the model on the basis of the circular ring model one has to use for discretisation of the tire section several circumferential lines, see figure 2. The deformation of the tire section produces bending moments and shear forces. For practical reasons one reduces this system to three lines, two shoulder an one zenith line. The coupling with circumferential belt forces was introduced from the lateral and longitudinal deflection equations of the belt. So it was possible to introduce the changing of belt tension stemming from tire deflection and regarding the contact patch pressure distribution in correct manner. Using the dynamic tire model cornering forces, driving and breaking forces and steering moments are computed. The out of plane tire dynamic is modelled by the modal forms up to 60 Hz during the rolling contact. Lateral to the wheel plane the belt is stiff and is only slightly bended in contact area by cornering force. The torsional circumferential movement of the wheel rim against the belt is introduced. Modal forms of the circumferential deformation of the belt are neglected regarding high longitudinal hysteresis of belt. Because of difficulties to distribute the energy loss to the several components of the tire structure damping and hysteresis of side walls are taken in account for lateral deformation using the dimensionless damping \( D \) belonging to the modal form. Thermodynamics of the rolling tire are not taken into account.

VTI RAPPORT 332 A
3. Dependence on friction-conditions

The degrees of freedom of the tire are (see figure 3):

\[ y_r = \text{lateral modal amplitude}, \gamma = \text{camber angle}, \phi = \text{torsion angle around vertical axis}, \varphi = \text{angle of wheel rotation and } \delta = \text{relativ movement of belt to rim in circumferential direction.} \]

Now for plane contact the dependency of changing tire parameters on tire forces are computed. All examples are computed on the CRAY, TU Berlin, and need a lot of computing time, because of the very short time increments \( t = 1/2500 \text{ sec.} \) that was used. As usual for drum measurements, the steering angle \( \beta \) is increased beginning from 0 to 15 degrees and also going back to 0.

In first example, figure 4 (Appendix), sliding and sticking friction coefficient was taking equal and also no bending flexibility of the belt and also no torsion of the belt around vertical axis was allowed. The tire parameters belong to a 155 SR 13 tire. Computation presents lateral deformation, longitudinal deformation, torsion around vertical axis, the cornering moment, the rotational velocity of the rim, the longitudinal force, the vertical force and the cornering force. The pressure distribution in contact area was taken to be constant in this first example.

In the second example, figure 5 (Appendix), the bending flexibility of the belt was introduced. Shown is only the cornering force and cornering moment. In the third example, figure 6, also the torsional elasticity around the vertical axis is introduced.
force coefficient becomes smaller, the cornering moment acting on the wheel is shown and also cornering moment on contact patch. In the fourth example, figure 7 (after introducing belt flexibility, torsional elasticity), also the friction function is introduced as a function of sliding velocity. Because of the high negative gradient of the friction function with sliding velocity strong oscillations occur. In the fifth example, figure 8, the actual pressure distribution is introduced. High frequency flutter occurs and the damping parameters should be increased to stabilize the model. This can be done by changing modal damping or by changing the friction function. In the sixth example, figure 9, the slope of the friction function with velocity was lowered and the resulting oscillations were also lowered. But it was necessary to introduce a plateau for the friction function to arrive at nonoscillatory tire behavior. Also the model damping has to be increased (figure 10).

Generally the examples show how to introduce the nonlinearity of friction to compute the short wave length and high frequency rolling deformations of the belt by numerical integration. Also great variety of forces of friction between tire and road can be used by introducing damping in the structure and it is possible to get nonoscillatory reaction of the model. On the other hand the explanation for sliding forces has to be remembered. A simple friction function can not explain the force generation between tire and road in correct manner. One needs more information on the physics of kinetic rubber/road material reaction and this not only for computational reasons, but also for technical reasons for using the best contact forces between tire and ground.

4. Conclusion for car-tire dynamics

The new tire model was used for computing open loop dynamics of a GOLF-passenger car. To save computing time the time increment was increased, so only the new generated area-algorithm was in action and the space step was larger then the contact length. In this case all high frequency-degrees of freedom of the system where locked. When rolling over an obstacle (step function 14 cm . 6 cm) this locked variables come into action to analyse the whole system. The system, see figure 11, has 30 DOF, the locked system only 11 DOF. In figure 12 the time history of some variables are shown. Also the difference between a front driven car and a rear axle driven car is shown in figure 13 starting with cero velocity.
Quantifying improvements of car or tire parameters one needs equations for driver-car interactions, i.e. a closed loop system. Some advances are made for a sequence of smooth curves of the road or full circuits. Figure 14a shows the GOLF-car on a circuit, radius 100 m, driving with low speed \( v = 17.5 \text{ m/sec} \). Figure 14b shows driving with higher speed \( v = 22.5 \text{ m/sec} \). Here stability of the system is lost for high speed \( v = 27.5 \text{ m/sec} \) the "driver" is not able to hold the car on the circle and it is sliding to outside. Using the same "driver-equation" for driving difficult lane change maneuvers it failed. So it seems that there is still the task to analyse the tire-car-driver interaction much more precise regarding the precise interaction between tire and road and also tire and car.

The Author thanks Deutsche Forschungsgemeinschaft (DFG) for supporting this research program.
Literature


Appendix

Figure 4a

STEERING ANGLE $\beta$, DEG

Figure 4b

CIRCUMFERENTIAL RELATIVE MOVEMENT OF BELT TO RIM $\bar{\bar{S}}$, CM

Figure 4c

LATERAL DEFORMATION $y_r$

first example, very simplified parameters
first example, very simplified parameters
first example, very simplified parameters
Appendix

Figure 5a

Figure 5b

second example, bending flexibility introduced
Appendix

Figure 6a

Figure 6b

third example, bending flexibility and torsional elasticity introduced
fourth example, adding friction as a function of sliding velocity
fifth example, adding realistic pressure distribution
Appendix

Figure 9a
CORNERING FORCE, daN

Figure 9b
CORNERING MOMENT

Figure 13
starting a front-axle driven and a rear-axle driven car

tslope of friction function lowered

VTI RAPPORT 332 A
stabilized dynamics of the slipping tire by friction function with plateau
Appendix

Figure 12a

open loop dynamics of a car rolling over an obstacle
Appendix

Figure 12b

open loop dynamics of a car rolling over an obstacle
Appendix

Figure 14a

Figure 14b

Figure 14c

closed loop dynamics of a car
on a circuit of radius of 100 m
ANTI-LOCK BRAKING SYSTEM PERFORMANCE. INTERNATIONAL REGULATIONS NOW AND IN THE FUTURE - SOME SWEDISH VIEW-POINTS

Olle Nordström, Swedish Road and Traffic Research Institute

ABSTRACT

The braking performance is one of the most important accident avoidance characteristics of a road vehicle. It is however not only the braking distance that must be considered during emergency braking but also stability and steerability. Wheel locking must be avoided on at least some wheels in order to meet these demands. Braking systems designed to perform this automatically irrespective of the applied pedal force are often called anti-lock braking systems (ABS). Such systems were first offered as optional equipment on some US passenger cars about 1970 and became standard equipment on US heavy vehicles from 1975 to 1978 and on a large volume European passenger car in 1985. Today most vehicle manufacturers offer at least optional anti-lock systems. A low cost system for cheaper models is already on the market and others are being announced.

The evaluation of the safety aspects of these very sophisticated systems is a difficult and expensive task. The importance of international performance test methods and requirements is therefore obvious.

The United Nations Economic Commission for Europe (ECE) has developed a large number of international road vehicle regulations. The ECE Regulation No. 13 addresses brakes and contains since 1979 an annex concerning requirements on anti-lock brakes. A revised version became effective in 1987. The same rules have also been adopted by the European Economic Community (EEC) in 1986.

The author took active part in the establishment of the revised version of the ECE-anti-lock regulation and has also been responsible for several studies concerning anti-lock system performance under winter conditions carried out by the Swedish Road and Traffic Research Institute (VTI).
This paper describes briefly the ECE anti-lock regulation and the VTI investigations. Based on these investigations winter service test methods and requirements are proposed to be added to the ECE/EEC-regulations. These are:

- J-turn braking test on ice
- Split-friction test with very low friction on one side
- Straight line braking on ice
- Transition from low friction to high friction surface

A hybrid laboratory test is envisaged as a future possibility of checking these performances for electronic anti-lock systems. In this test the vehicle is stationary and connected to a computer.
INTRODUCTION

The braking performance is one of the most important accident avoidance characteristics of a road vehicle. It is however not only the braking distance that must be considered during emergency braking but also stability and steerability. Wheel locking must be avoided on at least some wheels in order to meet these demands. Braking systems designed to perform this automatically irrespective of the applied pedal force are often called anti-lock braking systems (ABS). Such systems were first offered as optional equipment on some US passenger cars about 1970 and became standard equipment on US heavy vehicles from 1975 to 1978 and on a large volume European passenger car in 1985. Today most vehicle manufacturers offer at least optional anti-lock systems. A low cost system for cheaper models is already on the market and others are being announced.

The evaluation of the safety aspects of these very sophisticated systems is a difficult and expensive task. The importance of internationally accepted performance test methods and requirements is therefore obvious. Differences in climatic conditions between countries have however turned out to be a problem as well as nationally different technical solutions especially for heavy vehicles.

The United States National Highway Traffic Safety Administration (NHTSA) issued the first anti-lock performance regulations in the world in 1971 which became effective in 1975. This Federal Motor Vehicle Safety Standard FMVSS 121 concerned air braked vehicles only. In 1973 the American SAE published an extensive Recommended Practice SAE J 46 for testing of slip control systems (ABS). Due to several unfortunate circumstances NHTSA had to withdraw the anti-lock part of FMVSS 121 in 1978.

The United Nations Economic Commission for Europe (ECE) has developed a large number of international road vehicle regulations. The ECE Regulation No. 13 addresses brakes and contains since 1979 an annex concerning requirements on anti-lock brakes. A revised version became effective in 1987. The same rules have also been adopted by the European Economic Community (EEC) in 1986.
Sweden took active part in the establishment of the revised version of the ECE-anti-lock regulation but has still not adopted it in its national legislation. The author of this paper represented Sweden in this work and has also been responsible for several studies concerning anti-lock system performance under winter conditions carried out by the Swedish Road and Traffic Research Institute (VTI).

This paper describes briefly the ECE anti-lock regulation and the VTI investigations. Based on these investigations winter service test methods and requirements are proposed to be added to the ECE/EEC-regulations. These are:

- J-turn braking test on ice
- Split-friction test with very low friction on one side
- Straight line braking on ice
- Transition from low friction to high friction surface

A hybrid laboratory test is envisaged as a future possibility of checking these performances for electronic anti-lock systems. In this test the vehicle is stationary and connected to a computer.
The complete story of the development of the ECE anti-lock braking regulation Annex 13 in the ECE Regulation 13 from the very beginning can be found in P Oppenheimer's excellent paper on international braking regulations (2). Here only the latest version of Annex 13 which was finalised in 1985 and became effective in 1987 will be discussed.

In this new Annex 13, which entered into force as Annex X in the EEC Directive already in 1986, three new performance categories have been established for motor vehicles but not yet for trailers. The perhaps most important reason for introducing these categories was the introduction of the split-friction test with low friction on one side and high on the other. In this test presently manufactured anti-lock system equipped vehicles can behave in three different ways: 1) meet both the stability and braking efficiency demands, 2) meet only the stability demands, 3) meet none of the demands due to lack of steerability.

- Category 1 is the most sophisticated and must comply with all requirements in the annex. These vehicles are designed for optimum performance in terms of stability, steerability and braking performance under all conditions. It is represented by most passenger car systems and the systems for heavy air braked vehicles typically used in the Federal Republic of Germany, Scandinavia and Finland (Bosch and Wabco).

- Category 2 is equal to category one except that it does not have to comply with the braking efficiency requirements in the split-friction test. It is represented by typical US and UK anti-lock systems with "select low" axle control adapting the braking force after the lowest wheel friction.

- Category 3 which does not have to meet any split friction test requirements is the simplest and is typically represented by systems acting only on the rear axle. These ensure stability superior to a normal braking system because the rear wheels will not lock at full brake application even on low friction. Steerability can however be lost due to front wheel locking. Only axles or bogies with at least one
directly controlled wheel have to comply which relevant parts of the anti-lock annex. Category 3 vehicles must comply with the basic efficiency and stability requirements for vehicles without anti-lock system, i.e. the front wheels shall tend to lock before the rear wheels for all friction levels between 0.2 and 0.8. This may be demonstrated by calculation or practical tests.

The trailer systems presently in use are in fact either category 1 or category 2 from performance point of view. Against proposals from Sweden and the Federal Republic of Germany the majority of the ECE countries decided not to introduce categories for trailers which consequently are not subjected to any split-friction test. It can be noted that US and UK trailers are normally "category 2" and in Sweden and FRG only "category 1".

Figure 2.1 gives an overview of the performance requirements for motor vehicles and trailers equipped with anti-lock braking systems.

2.1 **Electrical failure indication** is required for all vehicles. Internal failure in the electronic controller is however not included. The failure indication must be visible from the drivers seat. Mechanical failure indication except for hydraulic leakage is not required.

2.2 **Service brake performance after electrical failure** outside the electronic controller must for motor vehicles be at least the same that is required after a hydraulic circuit failure in the normal braking system. The same applies for secondary performance where also a hand brake may be used. The electronic controller is regarded as not subject to failure mainly due to testing difficulties. For trailers there are no requirements.

The present Swedish brake regulations do not allow any reduction in the normal braking performance in case of ABS failure, and the US supplemental Notice of Proposed Rulemaking SNPRM 135 for passenger car brakes does only allow a reduction of 20% in service braking performance from 6.12 to 4.9 m/s².
For international harmonisation it is obviously desirable to find a common requirement. That the problems are real is illustrated by the fact that a wide spread antilock system with integrated antilock and electrohydraulic full power rear brake system will have no rear brakes after electrical failure in the hydraulic pump. Fully laden on friction 0.8 the vehicle will at best be capable of a deceleration of 4.8 m/s² (82% of the Swedish and 98% of the proposed US requirements).

2.3 Electromagnetic interference

The anti-lock system must not be adversely affected by electric and magnetic fields. Test procedures have been discussed but none has yet become part of the regulation. Manufacturers have to present test results to be approved by the technical service of the approving authority.

2.4 Operational speed range

The system must operate down to a speed of 15 km/h. This limit is too high for satisfactory winter service. State of the art permits 5 km/h. The upper limit is not specified but tests have to be made at 80% of the maximum design speed but not more than 120 km/h and 80 km/h for trailers.

2.5 Energy consumption

Requirements exist for motor vehicles of all categories and trailers. They are however mainly a concern for heavy air braked vehicles. Depending on the maximum design speed motor vehicles must perform an anti-lock operation time between 15 and 23 seconds in laden condition on low friction (0.3) followed by four stationary full brake applications without energy supply. At a fifth brake application at least secondary brake performance must be achieved with the vehicle laden. Trailers are tested unladen on high friction with 15 seconds of anti-lock operation without new air supply followed by five stationary brake applications. The air pressure at the last application must correspond to a braking force of at
least 22.5% of the axle load of the laden trailer. Motor vehicles authorized to draw a trailer shall have a 0.5 litre reservoir connected to the control line and the pressure at the fifth full application must be at least 50% of the pressure obtained at a full application from the initial pressure.

2.6 Adhesion utilization

Braking tests from 50 km/h with full pedal force application are required for motor vehicles on a high and a low friction surface in laden and unladen condition. The low friction must not exceed 0.3 but 0.4 may exceptionally be allowed if a suitable surface is not available. Trailers are tested unladen on a high friction surface. An adhesion utilization of at least 0.75 is required, defined as the braking ratio (Braking ratio = deceleration/gravity) (Zmax) with the anti-lock system in operation divided by the coefficient of adhesion (K). K is calculated from the mean braking ratio between 40 and 20 km/h measured with the vehicle itself using single axle braking at the highest constant input force without wheel locking from 50 km/h. In the case of category 3 vehicles and trailers Zmax is calculated from single axle antilock braking ratio in the same manner as K.
NEW ECE REGULATION 13 ANNEX 13 Effective 1987
(AND EEC DIRECTIVE 71/320 ANNEX X Effective 1986)

<table>
<thead>
<tr>
<th>REQUIREMENT</th>
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<tr>
<td>Utilization of high friction</td>
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<td>+</td>
</tr>
</tbody>
</table>

1) Only for axles with at least one directly controlled wheel
2) Trailer unladen on high friction surface

ADDITIONAL CHECKS
- Tests on high friction                         | +   | +   | +   | +   |
- Tests on low friction                          | +   | +   | +   | -   |
- High to low friction test                      | +   | +   | +   | -   |
- Low to high friction test                      | +   | +   | +   | -   |
- Split friction stability test                   | +   | +   | -   | -   |
- Split friction deceleration                    | +   | -   | -   | -   |

ECE REG 13 ANNEX 10
(EEC DIRECTIVE 75/524)
- Laden compatibility motor vehicle/trailer      | +   | +   | +   | +   |
- Adhesion utilisation                           | -   | -   | +3) | -   |
- Wheel-lock sequence/stability check            | -   | -   | +3) | -   |

3) Only for those axles without a directly controlled wheel

Figure 2.1 Overview of new anti-lock braking regulations in ECE Regulation 13, Annex 13 (EEC Directive 71/320 Annex X)
2.7 Additional checks

- **Sudden full brake applications** at high speed and low speed on high and low adhesion (friction) must give stable braking without locking of directly controlled wheels. The same tests with trailers only need to be made on a high adhesion surface.

- **High to low friction test** with transition speed 50 km/h must not result in locking of directly controlled wheels for such a long time as to cause instability or deviation from straight course. Trailers are exempted from this test.

- **Low to high friction test** with transition speed 50 km/h must give brake force adaption to the high level within "reasonable" time. Trailers are exempted from this test.

- **Split friction stability test** is only required for motor vehicles of category 1 and 2.

- **Split friction braking efficiency test** is only required for category 1 vehicles.

2.8 ECE Reg. 13 annex 10 and EEC 75/524 concerning adhesion utilization and stability for vehicles with normal brakes is not applicable to vehicles with anti-lock systems except for the following cases.

- Laden compatibility between motor vehicle and trailer. The relation between control pressure and laden vehicle braking ratio (deceleration/g) when the anti-lock system is not operating must be within prescribed limits for both vehicle types.

- Adhesion utilization and wheel-lock sequence/stability requirements in terms of calculated brake force distribution when the antilock system is not operating have to be met by category 3 vehicles. If this is not the case, practical tests with the antilock system working may be made on a high and a low friction surface in order to demonstrate braking efficiency and stability.
3 SWEDISH PROPOSAL FOR COMPLEMENTARY WINTER SERVICE REQUIREMENTS TO BE ADDED TO THE NEW ECE REQUIREMENTS

In Sweden icy winter roads can be expected for about six months of the year. Safe braking under these conditions is a considerable problem.

Anti-lock braking systems with good performance on ice are therefore expected to give a significant reduction in traffic accidents where braking is involved.

In the following winter test procedures and requirements are proposed which are based on results of investigations made by the Swedish Road and Traffic Institute (VTI) from 1980 to 1986. The tests are proposed as complementary winter service requirements to be added to the new ECE anti-lock braking regulation.

The test procedures are
- a driver controlled J-turn test on ice
- a more severe split friction test
- a straight line braking test on ice
- a transition test from low to high friction

For simplified testing a future hybrid laboratory test is envisaged.

The VTI investigations have been made with heavy vehicles and vehicle combinations from about 5000 to more than 65000 kg as well as for a number of passenger cars as shown in figure 3.1. Five different antilock systems for heavy vehicles and three for passenger cars have been tested. All but two systems were category 1. The two exceptions were category 2 air brake systems.
<table>
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</table>

Figure 3.1  Test vehicles
4 DRIVER CONTROLLED J-TURN TEST ON ICE

4.1 General

Vehicles with anti-lock systems on steered wheels will if they meet the requirements of a straight braking efficiency test and a split-friction test certainly possess some degree of steerability. The split-friction test can indeed be regarded as a kind of high friction steerability test. On very low friction surfaces a bad anti-lock system may, however, give either very poor stability or very poor steerability due to high slip levels and poor slip distribution between front and rear axles. In both cases the expected safety benefits will not be obtained and in the unstable case it might even be more dangerous to use such an anti-lock system than a normal brake system or vehicles with anti-lock system only on the rear axle. It is therefore essential to test the steering qualities during emergency braking on low friction in a special test.

This is also true for trailers as the steerability and stability of a vehicle combination depend also on the performance of the trailer.

4.2 Proposed test specifications

A driver controlled J-turn test on ice is proposed which is illustrated in figure 4.1 and has the following specifications.

- The track surface shall consist of ice with a lateral friction corresponding to a maximum cornering speed between 40 and 60 km/h.

- The test track has a 30 m long entrance corridor, 0.5 m wider than the vehicle, followed by a 100 m radius circular track 1.5 m wider than the vehicle.

The test procedure comprises

- determination of maximum steady state cornering speed $V_M$
- determination of the deceleration from the maximum speed $V_0$ from which the vehicle can be braked with full pedal force.
Figure 4.1  J-turn antilock braking test with driver control. Test track configuration

Figure 4.2  J-turn antilock braking test with driver control. Test results showing stability/steerability factor and braking efficiency E_{BY}
Optional reference tests are

- locked wheel straight line braking from 40 km/h on the same surface
- determination of an ECE-type maximum constant deceleration in the
  turn without wheel locking from 75% of \( V_M \) based on front axle
  braking.

4.2 Performance requirements

Proposed steerability/stability performance is

- to stay within the track boundaries with all parts of the tyre treads
- not to exceed a steering correction of +/- 180°
- to have a stability/steerability factor \( E_S \) not less than 0.64 where \( E_S = (V_0/V_M)^2 \), i.e. successful braking from 80 % of the maximum cornering
  speed.

The braking efficiency \( E_{BY} \) with the maximum cornering acceleration \( a_y \) as reference is proposed to be at least 0.5, \((E_{BY} = a_{XABS}/a_y \geq 0.5)\)

or

the efficiency \( E_{BL} \) based on the locked wheel deceleration to be at least

0.90, \((E_{BL} = a_{XABS}/a_{XL} \geq 0.90)\)

or

the efficiency \( E_{BE} \) based on the maximum deceleration without wheel
locking to be at least 0.75, \((E_{BE} = a_{XABS}/a_{XE} \geq 0.75)\).

The test is also proposed for trailers which should be tested in
combination with an approved anti-lock motor vehicle.

4.3 Test results

Results from the closed loop J-turn test are presented in figure 4.2, 4.3
and 4.4.

Figure 4.2 illustrates the relationship between the stability/steerability
factor \( E_S \) and the braking efficiency \( E_{BY} \) for passenger cars and heavy
duty vehicles.
Figure 4.3 presents the relationship between $E_5$ and $E_{BL}$ also with separate results for passenger cars and heavy duty vehicles.

Figure 4.4 shows the relationship between $E_5$ and $E_{BE}$ for passenger cars.

The diagrams show no correlation between the stability/steerability factor and the braking efficiency. Results from tests with increasing initial speed have given both increasing and decreasing braking efficiency depending on the tyre equipment. From the diagrams can be seen that if all results were to be accepted, $E_5$ should be at least 0.5 instead of the proposed 0.64. The latter choice is based on the opinion that this value is more representative for the state-of-the-art. The vehicles that did not meet this requirement should be improved.

![Diagram showing the relationship between $E_5$ and $E_{BL}$ for heavy duty vehicles.]

![Diagram showing the relationship between $E_5$ and $E_{BL}$ for passenger cars.]

Figure 4.4 J-turn antilock braking test with driver control. Test results showing stability/steerability factor and braking efficiency $E_{BL}$.

![Diagram showing the relationship between $E_5$ and $E_{BE}$ for passenger cars.]

Figure 4.5 J-turn antilock braking test with driver control. Test results showing stability/steerability factor and braking efficiency $E_{BE}$. 

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5 SPLIT FRICTION TEST WITH VERY LOW FRICTION ON ONE SIDE

5.1 General

The split-friction test which is already part of the ECE/EEC-regulations is illustrated by figure 5.1. The test track consists of two parallel tracks, one with a high friction K1 and the other with a low friction K2. The test is performed from an initial speed of 50 km/h in three steps.

The two first steps give the values of K1 and K2 by means of maximum constant pedal force single axle braking without wheel locking. The third step gives the split-friction ratio Z3.

The ECE/EEC performance requirements are

- a maximum lateral displacement where no part of the tyre treads cross the common track boundary
- a maximum steering correction of 120 degrees within the first two seconds and 240 degrees during the rest of the stop
- a minimum braking ratio $Z3 \geq 0.75(4K2+K1)/5$ but not less than the low friction K2.

The last requirement in combination with an allowed ratio K2/K1 as high as 0.5 is a major weakness in the regulation as it allows an efficient "select low" system to pass the test. This type of system adjusts the total braking force to the low friction.

5.2 Proposal for winter condition requirements

As a realistic compromise it is proposed that the braking efficiency formula should be based on the actually achieved anti-lock braking ratios Z1 and Z2 instead of 75% of K1 and K2 and become $Z3 \geq 0.2 (4Z2+Z1)$. It is also proposed that the ratio $Z2/Z1$ must not exceed 0.4 and $Z2$ not 0.15. It is furthermore proposed that the applicable requirements should also be met by trailers as they can represent a large part of the total combination mass. The trailer should be tested together with a representative towing
vehicle equipped with an approved anti-lock system. The braking efficiency of the trailer should also be tested by means of separate trailer braking. When $Z_1$, $Z_2$ and $Z_3$ are calculated the rolling resistance of the towing vehicle can be set to 0.015 for driven wheels and <0.01 for non driven wheels.

**SPLIT FRICTION TEST**

ECE/EEC: $K_{1\text{min}}=0.5 \ K_{2\text{max}}=0.5K_1$

$Z_3\geq0.75(4K_2+K_1)0.2 \ Z_3^2 \ K_2$

![Diagram of split friction test](image)

**Figure 5.1 Split friction test procedure**

The very poor performance of a select low system is demonstrated by figure 5.2 which shows that $K_2=0.1$ gives about 60 m longer braking distance from 50 km/h compared to a fully individual wheel control system. The difference between the ECE/EEC and the proposed requirement, which was first formulated by E. Petersen from WABCO, is also shown.
5.3 VTI tests and test results

VTI has performed tests on split friction surfaces with ice as low friction surface having peak and locked wheel friction coefficients 0.1 with standard tyres and sand bonded to the ice with water as high friction surface giving a friction coefficient of about 0.6. The test speed was 50 km/h. Anti-lock braking tests were performed on the low and high friction surfaces for reference purpose. Part of the test program also included measurement of the friction coefficients $K_1$ and $K_2$ according to ECE/EEC regulations. This was done with front axle braking without wheel locking.

Passenger cars, heavy trucks and truck trailer combinations with commercially available systems and also one prototype system (see figure 3.1) have been tested. The systems represent different control strategies from "select low" that adapt to the low friction to individual wheel control.
Results

In figure 5.3 the braking ratio $Z_3$ obtained in the split friction test is compared to the optimum braking ratio defined as $(Z_1 + Z_2)/2$. The braking ratios $Z_1$ and $Z_2$ are those obtained by anti-lock braking tests on the high and low friction surfaces with the vehicle in question. Braking ratio is defined as the mean deceleration divided by gravity acceleration (9.81 m/s²).

It can be seen that the select low systems have a braking efficiency of only 27-45% of the optimum braking ratio compared to values between 67 and 90% for systems with a higher degree of individual wheel control. In figure 5.4 the braking ratio $Z_3$ is compared to a minimum required braking ratio $(4Z_2+Z_1)/5$ proposed by E Petersen from WABCO. The tested vehicles with select low anti-lock systems did not meet this requirement. In figure 5.5 test results are compared with the ECE/EEC requirement $Z_3 \geq 0.75(4K_2+K_1)/5$. The ECE/EEC requirement was easier to meet than that from WABCO.

![Figure 5.3 Split friction test results. Comparison with optimum performance](image-url)
5.4 Split friction braking performance of vehicle combinations with and without anti-lock system in operation

In 1984 split friction tests were also carried out in order to compare performance with and without anti-lock system. Four unladen heavy vehicle combinations (vehicles 6, 7, 10 and 11 in figure 3.1) were used. All were equipped with load sensing valves and WABCO anti-lock systems. Three drivers took part in the test but each combination was tested by only one driver.

The result of these tests was that the braking efficiency in most cases was 10-20% higher with the normal braking system than with the anti-lock system in operation. The efficiency of the anti-lock systems was about 80% of \((Z_1 + Z_2)/2\). Both with and without anti-lock system it was possible to keep the vehicle within a 3.5 m lane. The steering and braking task was, however, more difficult without anti-lock system. The maximum steering angles were about 90 degrees with and 135° without anti-lock system.
6 STRAIGHT LINE BRAKING ON ICE

6.1 General

Straight line braking on a homogeneous surface is the classic and basic way of testing the braking performance of vehicles. The ECE/EEC anti-lock braking regulations prescribe straight line low friction tests. The friction level is however allowed to be as high as 0.4. A test on ice is therefore regarded as a useful winter service approval requirement.

6.2 Tests carried out by VTI

Straight line anti-lock braking tests on ice have been made in comparison with

- locked wheel braking
- best driver control braking
- peak friction measured with single axle braking according to ECE/EEC anti-lock regulation
- standard reference tyre friction coefficient measured with the Swedish constant slip (13-15%) friction test vehicles BV11 and BV12 (see figure 6.1 and 6.2) measured at 40 and 20 km/h. BV11 had a 4.00-8 tyre and BV12 a 5.60-15 PIARC "Europe" tyre both with rib tread, in accordance with ISO TR 8349 on friction measurement.

Tests have been made from initial speeds ranging from 70 to 35 km/h for trucks and trailers and, for passenger cars from 110 to 50 km/h.

Most of the tests have been done in the temperature range -50°C to -200°C but tests have also been made near 0°C and down to -30°C. Except in 1980 the tests have been made on ice roughened by the special multiwheel trailer with studded passenger car tyres shown in figure 6.8. The treatment results in a somewhat higher and more uniform friction and reduces polishing effects which tend to lower the friction.
6.3 Results

The results are summarized in figure 6.3, 6.4, 6.5, 6.6 and 6.7.

From the figures can be seen that as a rule the braking efficiency with anti-lock systems is higher than with locked wheels and higher than best driver performance. In tests with laden and unladen vehicles the unladen vehicles tend to get higher deceleration but not necessarily higher braking efficiency based on peak value.

The 75% efficiency required by ECE/EEC regulations is not always met on ice by anti-lock systems for heavy vehicles. For the tested passenger cars with and without studs the efficiency is close to 100%.

Longitudinal friction coefficients obtained with the reference tyres on friction test vehicles BV11 and BV12 according to the constant slip method gave the same values as the peak friction coefficients obtained by single axle braking according to ECE Regulation 13 both for a truck and a passenger car with standard tyres (0.17).

6.4 Discussion

According to Annex 10 in ECE regulation 13 are normal brakes allowed to have a braking efficiency of 50% at a friction coefficient of 0.2. It could therefore be debated if the efficiency requirements on anti-lock systems on ice should be as high as 75% of the peak friction coefficient. The test results indicate that 90% of the locked wheel friction could be a more suitable requirement. A locked wheel test is also the simplest and least expensive alternative. In order to avoid stability problems the locked wheel braking tests on ice are recommended to be done from an initial speed of 40 km/h.

6.5 Proposal for a straight ahead braking test on ice

Based on the field test experience and theoretical considerations the following test is proposed.
**Test surface:** The test surface should be ice with a locked wheel friction of 0.1±0.05 or a peak friction of 0.20±0.05 measured with the test vehicle itself or the friction test vehicle BV11 or equivalent equipment. Roughness of the icy by means of the special multiwheel trailer according to figure 6.8 is recommended. The air and ice surface temperature should be below zero °C, preferably between -5 and -15°C.

**Test speed:** The initial speed should be 40 km/h for vehicles with tyres without studs and 50 km/h for tyres with studs (additional test for passenger cars).

**Braking tests:** Locked wheel and anti-lock braking stops should be made with a pedal force that on high friction would give at least 5 m/s². The mean value of the results from at least three tests of each type should be used for the efficiency calculation. For each test the mean deceleration is calculated by the formula $\ddot{a}=5.56/T$ m/s² where $T$ is the time from $V=35$ km/h to $V=15$ km/h.

**Minimum requirement on braking efficiency:**

$\frac{\ddot{a}_{ABS}}{\ddot{a}_L} \geq 0.9$ or $(\frac{Z_{ABS}}{Z_{LOCK}}) \geq 0.9$

$\ddot{a}_{ABS} = \text{Mean deceleration with the antilock system operating, } Z_{ABS} = \frac{\ddot{a}_{ABS}}{9.81}$

$\ddot{a}_L = \text{Mean deceleration with all wheels locked, } Z_{LOCK} = \frac{\ddot{a}_L}{9.81}$

**Trailer tests:** Trailer tests should be made by braking only the trailer and correcting for the rolling resistance of the towing vehicle. The rolling resistance coefficient for non-driven wheels may be assumed to be 0.01 and for driven wheels 0.015.

**Alternative test method:** Tests may also be performed according to the procedure prescribed by ECE/EEC regulations but on the same ice surface. It is considered as more difficult to carry out and meet the requirements of this test.
Figure 6.1 Friction test trailer BV11

Figure 6.2 Friction test vehicle BV12

Figure 6.3 Straight line antilock braking efficiency in relation to locked wheel braking.
Figure 6.4 Straight line antilock braking test results. Comparison with test driver performance

Figure 6.5 Straight line antilock braking test results. Comparison with ECE/EEC friction coefficient

Figure 6.6 Straight line antilock braking test results with standard tyres. Comparison with friction test trailer BV11

Figure 6.7 Straight line antilock braking test results with standard tyres. Comparison with friction test vehicle BV12

Figure 6.8 Multiwheel trailer with studded passenger car tyres for ice conditioning treatment
7 TRANSITION TEST FROM LOW TO HIGH FRICTION

7.1 General

When a vehicle with normal brakes is braked on very low friction and suddenly encounters a transition to a high friction surface the braking torque applied by the driver is immediately fully utilized up to the limit of adhesion for each axle as they pass on the new surface.

In the same situation but braking a vehicle with an antilock system fully adapted to the low friction there is a risk that the pressure recovery might be very slow and result in an unacceptably long braking distance compared with a normal braking system. The new ECE/EEC antilock braking regulations therefore demand a test in this respect. The requirement on the high/low friction ratio is however only 2:1 which is low for winter service conditions.

7.2 Tests carried out by VTI

Tests with one heavy duty truck antilock system on ice with very low friction resulted in pressure drops to near zero with recovery rates of not more than 3 bar/sec that could not be influenced by a sudden transition to high friction. This corresponds to about 1.5 seconds to reach 4.5 m/s² deceleration. Transition tests with other systems indicate that 0.7 seconds is a reasonable target from a technical point of view.

7.3 Discussion

If the vehicle deceleration is measured the wheelbase has to be taken into account. At 50 km/h an additional time delay of 0.7 seconds will cover all practical cases. A total deceleration transition time from 1.5 m/s² to 4.5 m/s² of 1.5 seconds for heavy duty vehicles and 1.0 second for passenger cars has been considered to be a reasonable requirement for winter service.
7.4 Proposed winter service test

The test shall be made with full brake application at a pressure that corresponds to a deceleration of at least 5 m/s² starting on a low friction surface which must not give the vehicle a higher deceleration than 1.5 m/s² with the antilock system in operation. The vehicle speed at the transition to high friction must not be less than 50 km/h. The high friction surface must allow an antilock braking deceleration of at least 4.5 m/s². This deceleration must be reached within 1.5 seconds for heavy duty vehicles and within 1.0 seconds for passenger cars. This time is measured from the front axle transition time.
HYBRID LABORATORY TESTING - A FUTURE TYPE APPROVAL PROCEDURE?

The practical difficulties are considerable both technically and economically in obtaining test tracks that give the desired friction characteristics and are large enough for safe high speed and cornering tests. In fact they are so severe that ECE/EEC regulations regard peak friction coefficients up to 0.4 at 0 to 50 km/h as low and do not specify speed or slip characteristics of the tyre/road adhesion. Furthermore the problems connected with brake lining characteristics must not be forgotten.

For antilock systems with electric wheel speed signals these problems can be eliminated by real time computer simulation of the tyre/road characteristics; brake torque characteristics and vehicle motion dynamics including wheel speed sensor signals. The real vehicle that is to be tested is connected to the computer through an interface so that the simulated wheel speed signals are received by its antilock system controller and the wheel brake cylinder pressures measured by sensors on each wheel are fed back to the computer. During the test the vehicle is stationary in the laboratory with the engine running. The test engineer has only to apply the brakes after starting the computer program.

This technique has been used by VTI with promising results.

At present it is possible to simulate:

- Straight braking on a homogeneous surface
- Straight braking on a split friction surface with steering corrections based on yaw motion
- Braking during steady state cornering with constant steer input
- J-turn braking with constant steer input applied at the same time as the brakes
- Braking on a surface with changing friction can also be simulated as the computer programme contains two tyre models for each wheel

Validation simulations have been made with a two axle truck with an unladen weight of 6 500 kg and a laden weight of 13 000 kg. The vehicle
was equipped with three different types of antilock systems. This vehicle was also used in the already mentioned tests on real ice tracks, split friction tracks as well as on high friction tracks.

The following tests were used for the validation:

- Straight braking on homogeneous ice. Initial speed 10 and 20 m/s
- Straight braking on a split friction surface. Initial speed 10 m/s
- J-turn braking on ice with constant steering input corresponding to 100 m radius applied at the same time as the brakes. Initial speed 11 m/s
- Straight braking on a high friction surface with the peak friction coefficient 0.6. Initial speed 30 m/s

In all the tests the ranking order in performance was the same in simulation and real test. The general characteristics in terms of deceleration, lateral acceleration and yaw behaviour over time were also quite well reproduced. This also applies to wheel speeds and brake pressures. Test were made both with identical tyre data on front and rear wheels and with somewhat reduced friction on the rear wheels. The best results were obtained in the latter case. This is in line with the fact that ice friction is reduced by the polishing effect of slipping tyres. In this case the front tyres polish the ice for the rear tyres. It is not believed that this method of testing can replace real world tests but it looks promising as a future complement for evaluating antilock system performance under conditions that are too difficult, expensive or dangerous to require in real type approval tests.
9

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Periodic vehicle inspection in Sweden - experiences and viewpoints

In the beginning of the 1960s it was considered necessary to take action in all fields affecting the traffic safety in Sweden in order to curb the rising numbers of killed and injured.

As a part of the action program, Sweden introduced periodic vehicle inspections in 1965. A state-owned, special company was formed, which now operates over 170 inspection stations and carries out more than 4 million inspections every year. The costs are covered by fees, fixed by the government. Inspections are annual from two years' age.

The main purpose of periodic vehicle inspections is to improve the traffic safety standard of the vehicles by eliminating safety defects which can lead to accidents. The detection of vehicle safety defects and their subsequent rectification are thus the direct results of the inspections. But periodic inspections also have an impact on vehicle manufacturers, the motor repair trade, governmental authorities, vehicle owners etc, which gives important indirect results.

During the first 10 years after the introduction of periodic inspection the useful life of passenger cars increased about 50% in Sweden, and it has continued to increase. Thus the required size of vehicle population has been maintained with a lower number of new cars per year. The number of new cars the Swedes did not have to buy can be calculated to be about 100 000 per year, representing savings of over 10 times the total costs of the inspections.

The statistical reports published every year by the inspection company show how the safety standard of the vehicle population in Sweden has improved over the years since 1965, in spite of the increased age.

A study made by the New Jersey Institute of Technology some years ago indicated that the New Jersey system of periodic vehicle inspection produced safety effects which repaid the total costs of the inspections approximately two-fold. A study of the same kind was carried out in Sweden in 1984, with similar results. The Swedish study indicates that the periodic vehicle inspection has contributed about 10% to the improvement in traffic safety. This means that also in Sweden the periodic inspections have more than well repaid the total costs by the safety effects achieved.

Although the inspection system is thus more than cost-effective in its present form, studies have indicated that its efficiency could be improved, e.g. by re-allocating resources in accordance with the observed differences between the various vehicle categories and age groups. More frequent inspections of heavy vehicles and older vehicles are likely to increase the cost-efficiency of the Swedish inspection system.
PERIODIC VEHICLE INSPECTION IN SWEDEN - EXPERIENCES AND VIEWPOINTS

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General background

Sweden introduced periodic inspection of all registered motor vehicles and trailers in 1965. The present rules, effective from 1971, stipulate that the vehicles have to be inspected annually from the second year after their model year designation. This means that in 1987 all 1985 and earlier models have to be inspected. Stricter rules apply to public service vehicles, emergency vehicles, driving school cars and cars for rental.

Over 170 inspection stations, varying in size, are operated by a special state-owned company, AB Svensk Bilprovning (The Swedish Motor Vehicle Inspection Company). The location of the stations follows the distribution of the population - about 94 % of the vehicle owners live within 30 km from the nearest inspection station and the average distance is 10 km. The inspection company is a joint-stock company. The government has a dominating influence in the company and holds the majority of the shares. The remainder is divided between the motorists' organizations, the motor insurance companies and the motor repair trade organization.

The company is financed solely from inspection fees with no subsidies from the government and is not supposed to make any financial profit.

The company carries out almost 5 million inspections per year, over 90 % of which are periodic inspections.

The company has its own training school, where all inspectors get their basic training and advanced training. Refresher courses are held regularly. Prior to employment as a vehicle inspector the new recruit must have several years' experience as a motor mechanic (or a degree in engineering) and he is not permitted to carry out inspections on his own until he has completed a one-year training period, some six weeks of which will be spent at the school.

The periodic inspection is mainly a technical examination of the vehicle, with the purpose of checking its traffic safety standard. Therefore the inspection comprises an examination of those vehicle components which are considered to be of greatest importance to traffic safety. The technical examination is carried out according to an inspection program in which inspection methods for the different components are specified. Defects observed are assessed in accordance with standards laid down by the National Swedish Road Safety Office.
The widely varying inspection systems existing in the world today show that vehicle inspection can take many forms. Technical, economical and social conditions may influence the design of the vehicle inspection system. This applies to the organizational structures and the legislative framework for the inspections as well as their technical contents.

The role of the vehicle as a cause of accidents is not very well known. Partly, this is due to the fact that there is no simple method to clarify the exact mechanisms of accidents and establish their real causes. Most in-depth accident investigations seem to imply that there is nearly always a multitude of causative factors. The factors may have varying importance, but no single factor can be given the whole blame and the elimination of any one of them, such as e.g. a vehicle defect (bald tyres, uneven braking) could mean that the chain of events leading to the accident was broken. Generally, available accident statistics do not specify the real causes of accidents, just give a rough classification based on the findings in police investigations. However, studies carried out in some countries indicate that vehicle defects have been causative or contributory factors in quite a large number of accidents.

The main purpose of periodic vehicle inspections is to improve the traffic safety standard of the vehicles by eliminating safety defects. Since 1971 also the environmental aspects of the vehicles have been included in Sweden. Unfortunately exact figures cannot be stated, neither as regards the potential for traffic safety and environment improvement, nor as to what extent the vehicle inspection system in Sweden is successful in exploiting this potential.

A hint about the size of the safety potential may be the results obtained in Finland. In 1968 Finland started a project which has developed so that by now 13 multi-disciplinary investigation teams with a total of 185 members are available for accident investigations. Among their findings are that human factors have an influence in 97% of the traffic accidents, environmental factors in 45%, and vehicle factors in 23% of the accidents. The conditions in Finland do not differ too much from those in Sweden, so the results should not be too far from what could be obtained in Sweden.

**Improved vehicle safety standards**

It is easy to demonstrate with material from the statistical reports published every year by Svensk Bilprovning, that the safety standard of the vehicles has improved over the years since 1965.

When inspected in 1965 over 80% of the private cars, five years old or more, had one or more defects. The corresponding figure from the inspections in 1985 was 74%. But during the period from 1965 to 1985 a number of new requirements were introduced, e.g. for windscreen washers, seat belts and headlamp cleaners, and were included in the inspection. In the beginning
of the 1970s checking of the exhaust gases from motor vehicles was included in the periodic inspection. The number of observations on defects in 1985 would have been lower if defects depending on such new requirements were excluded. Also, the service life of the vehicles has increased, and thus the number of older vehicles was much higher in 1985 than in 1965. In 1965 only a few percent of the vehicle population was over 14 years old. In 1985 the group 14 years old and older vehicles constituted almost 20 % of the population.

One way to demonstrate the changes is to show the relative numbers of observations on defects. The following diagrams illustrate the development. The first shows the number of defects observed per 100 inspected passenger cars in different age groups when inspected in 1965, 1969 and 1973. The second shows the corresponding results in 1977, 1981 and 1985. Only graphs for every fourth year are shown, for reasons of clarity.
The improvements were bigger in the first years after the introduction of periodic inspection. The number of defects per 100 inspected passenger cars eight years old, for instance, dropped from 340 in 1965 to 250 in 1969, and was about 190 in 1973. For the age groups 5-8 years there was almost a 50% reduction in the number of defects per 100 inspected cars from 1965 to 1973.

During the period 1977-1985 the improvements have been smaller, about 25-30% in the age groups 5-8 years. Also, a slight increase in the number of defects has been observed for the oldest vehicles between 1981 and 1985. While these age groups previously were very small and contained mainly well-preserved vehicles destined to be future "veterans", they are now quite big and include a large number of cars in everyday use. It should be noted that the diagrams are not directly comparable, due to changes in the report forms and the extent to which defects are specified. Without these changes, which took place in 1976, the numbers of defects in the second diagram would have been about 10% lower. Also, it should be kept in mind that the development illustrated in the second diagram is influenced to some extent by the new items added to the inspection program because of new requirements.

In order to get a clearer view of the improvements the observation frequencies for such systems which have not been subject to any new requirements may be studied in comparable age groups. One such system is the steering mechanism. The following diagram shows the observation frequencies for 5, 6, 7 and 8 years old passenger cars inspected in 1965, 1975 and 1985.

The changes for the six- and seven-year-old cars between 1965 and 1975 represent roughly a 50% reduction in observation frequency. For the eight-year-old cars the reduction is even bigger, from 23 to 7%. For the five-year-old cars the reduction is from 9% in 1965 to 6% in 1975 and 3% in 1985.
Although the actual figures differ, the same trends will be observed for all the different main systems of the vehicles in Sweden. It can e.g. be seen that the percentage of cars with observations on defects in the structure has decreased considerably since the middle of the 1960s. The observation frequency for six-year-old cars decreased from 14 % in 1965 down to 1 % in 1985.

If a vehicle has very serious defects a traffic prohibition is served. The number of such cases has also decreased continuously since 1965. That year the prohibition frequency was about 13 per one thousand vehicles inspected but it had dropped to about 0.7 by 1985.

Over the years a certain pattern as regards the reasons for the prohibitions has been regarded as normal. About 70 % of all the prohibitions have always been due to brake failures because of leaking brake lines, i.e. corroded brake pipes and chafed hoses.
The remaining 30% have always had a variety of reasons. However, in recent years this pattern has started to change. In the 1980s increased numbers of prohibitions because of corroded suspension components also in relatively young cars have been registered. This is reflected by the slight increase in the graph for 1985. Since such defects can lead to sudden loss of control over the vehicle and have been found in cars only 4-5 years old, the trend must be considered alarming.

While the younger age groups among the vehicles generally show quite substantial reductions in observation frequencies, this is not always the case for the older vehicles. In the age groups over 10 years old an increase in observation frequencies has been observed for the propulsion system, the braking system and the communication system, while the body and the steering have had almost constant figures over the years. Only for the structure and for the wheel system, which consists of wheels, suspension and shock absorbers, a small decrease has been observed over the latest 10 years also for the oldest vehicles.

However, in later years the results also for the 10-year-old and older ones are slightly influenced by the additions to the inspection program due to new regulations. In particular, the headlamp cleaners which were made compulsory from 1974 models, have proved to have rather high observation frequencies which affect the results for the communication system.

The statistical reports show very clearly how the observation frequencies increase as the vehicles grow older and accumulate more mileage. For every type of vehicle and each component a typical pattern can be established, but the levels and the rate of increase of the observation frequencies vary considerably.

It has already been mentioned that the service life and thus also the average age of the vehicles have increased. The development as regards the age distribution can easily be traced from as far back as 1971 for passenger cars, and from 1976 for heavy trucks (over 6 tons GVW). The proportion of passenger cars older than 10 years when inspected has grown from 11.8% in 1971 to 38.4% in 1986. The corresponding figures for the heavy trucks are 14.8% in 1976 and 35.8% in 1986. Overall figures for all kinds of vehicles are about 22% older than 10 years in 1976 and about 40% older than 10 years in 1986.

The increasing proportion of older vehicles with higher observation frequencies and the additional items introduced into the inspection program have meant that the overall observation frequency and the failure rate have remained more or less constant over the years from 1971 until today. The overall failure rate has been just over 20% during this period, but was considerably higher 1965-1970. The failure rate varies considerably between the different kinds of vehicles. In 1986 23% of the passenger cars were failed, 24% of the heavy trucks and 31% of the heavy trailers, while buses had a failure rate of 10% and motorcycles 8%.
Improved traffic safety

It must be assumed that the effect on the traffic safety achieved through the vehicle inspections is due to a reduced number of safety defects and reduced time/mileage in defective condition for the vehicles operating in traffic. During the latest four years over 5 million defects per year have been noted in the inspection reports for the passenger cars, the numbers of which have increased from 2.7 to 2.9 million in the same time. Since the start of the inspections in 1965 the total number of observations on defects is well over 100 million.

The improved safety standard of the vehicles in Sweden has certainly had an influence on the reduction of the accident rate. Unfortunately, there is no easy way to establish the extent of this influence, because accident reduction is the joint effect of combined and simultaneous efforts in many fields, besides the vehicle inspections.

It is also difficult to assess the effects of periodic inspections during a period when there have been legislative changes affecting traffic safety and improvements in roads and signalling, as well as changes in driving standards, vehicle speeds and police enforcement.

In Sweden the trend of rising numbers of fatalities in traffic was broken in the middle of the 1960s and the numbers have been going down continuously for over 15 years. The same applies if injured persons are included. This encouraging development in Sweden is of course the collective result of many years of struggle to achieve improvements in all areas with an influence on the traffic safety. But there is little doubt that quite a substantial part of the traffic safety improvement is due to the improved vehicle safety standards which are the results of the periodic inspections and the new requirements. Unfortunate-
ly a new turning point was registered in 1982–83 and the numbers of fatalities and injured are rising again.

In order to establish exactly how much vehicle inspection has contributed to this positive development we would have to find out how many accidents that did not occur thanks to the inspections, and then also calculate the costs to the society for these non-occurring accidents. This is impossible and we therefore have to accept statistical methods with a lower degree of precision.

A study made at the New Jersey Institute of Technology about five years ago employed multiple regression analysis and indicated that the New Jersey system of periodic vehicle inspection, which is not too much unlike the Swedish system, had produced safety effects which had repaid the total costs of the inspections approximately two-fold.

A study of the same kind was carried out in Sweden in 1984 by the Swedish Road and Traffic Research Institute (VTI). Its results were similar to the New Jersey study and indicated that the Swedish vehicle inspection system, together with campaigns in connection with the introduction of right-hand rule of the road, has led to "some 10 per cent improvement in traffic safety", the main part of which should be attributable to the inspections. The switch over from left-hand to right-hand traffic occurred in 1967 and should be the reason for the dip in the fatality graph for 1967 in the diagram above. Instead of the massacre predicted by some, over 200 lives were saved by the strict speed limits, extra supervision and intense propaganda before and after the switch.

The costs of the periodic vehicle inspections in Sweden

The costs of periodic vehicle inspection in Sweden can be specified as

- inspection fees
- transport costs (driving to and from the inspection station)
- time costs for transport, waiting and inspection
- administration costs (at the Register Department of the Swedish National Road Safety Office)

When accounting for the costs of vehicle inspections also the costs for repairs should be included. However, as will be seen below (p 11), such costs were more than balanced by the corresponding benefits in Sweden, and therefore have not been included.

The costs and benefits of periodic inspections were subject to an analysis a few years ago and the year 1979 was selected because it was the latest calendar year with complete data available. A special public committee had made an in-depth study of the costs of traffic accidents during that calendar year. There
is every reason to believe that a repeated analysis, based on a later calendar year, would give more or less the same results as regards the balance of costs and benefits, although the actual level in monetary terms would be higher.

**Inspection fees**

During the 1979 calendar year the total intake of inspection fees as regards the periodic vehicle inspections and re-inspections, was SEK 254 million. Since the inspection company is run on a non-profit basis and has a policy to relate fees as closely as possible to the actual costs, the fees can be regarded as representing the actual direct costs for the inspections.

**Transport costs**

These costs are made up of the added consumption of oil and fuel plus extra wear because of the trips to and from the inspection station. For 1979 they have been estimated to be SEK 0.50 per km. The average distance for the return trip was 20 km and the number of trips was 3.6 million. This means 3.6 x 20 = 72 million vehicle km and total transport costs of SEK 36 million.

**Time costs**

The average time for an inspection visit (transport to and from the inspection station, waiting and inspection time) was calculated to be 1 h 15 min. This means a total time of 3.6 million x 1 h 15 min = 4.1 million h. The calculated average value of one hour was SEK 20 in 1979. Thus the total time costs were 4.1 million x 20 = SEK 82 million.

**Administration costs**

The National Road Safety Office specified the costs for summons to the vehicle owners and registration of inspection results in 1979 to SEK 23 million.

**Total costs for periodic vehicle inspections in 1979**

The total costs for the periodic vehicle inspections in Sweden during the calendar year 1979 were thus

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<td>Inspection fees</td>
<td>254 million</td>
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<td>Transport costs</td>
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<td>Time costs</td>
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<td>Administration costs</td>
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<td><strong>Total costs</strong></td>
<td><strong>SEK 395 million</strong></td>
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Benefits from the periodic vehicle inspection in Sweden

The public committee studying the costs of road traffic accidents in 1979 found that the total costs were at least SEK 4 300 million. This amount does not include losses in so-called human values, which cannot be quantified.

Between the years immediately before 1965, when the periodic vehicle inspection was introduced, and 1979, the number of fatalities and seriously injured in traffic per 100 000 vehicles decreased by over 50%. In other words, the risk of a fatality or serious injury in 1979 was less than half compared to the risk in the years immediately before 1965. If this decrease had not occurred, there is every reason to believe that the total costs for traffic accidents would have been more than twice the calculated amount, i.e. over SEK 8 600 million. If such a simplified calculation method is accepted, the improved traffic safety can thus be price-tagged. It represented at least SEK 4 300 million in 1979.

Benefit from safety improvements

Since the improved safety standards of the vehicles due to the periodic vehicle inspections have contributed about 10% to the reduction in direct traffic accident costs, this effect alone is sufficient to justify the statement, that the periodic vehicle inspections do not constitute a burden to the society’s economy.

Benefit from reduced fuel consumption

Among the more directly quantifiable effects of the periodic inspections are their effects on fuel consumption because of the exhaust emission checks. Vehicles which exceed the permitted emission levels have to be repaired or adjusted. Several studies in UK, FRG and USA have shown that quite substantial savings are possible by correct adjustments to the engines. A very conservative assumption of some 2% savings corresponds to a total amount of some SEK 400 million in 1979. About half of this was energy taxes, but some SEK 200 million represented direct savings for a nation having to import all its oil-based fuel.

Benefit from increased life of cars

As stated in the foregoing a life expectancy increase has been observed since the periodic vehicle inspections were introduced in 1965. During the first 10-15 years after the introduction of periodic inspection the useful life of passenger cars increased about 50% in Sweden, and it has continued to increase also in later years.
The increased service life and the larger proportion of older cars in traffic have not resulted in lower safety standards. Instead, the safety standard has been improved in all age-groups as compared to 1965 and earlier years. And this has not been achieved at the price of increased costs for repairs - reports indicate that the total amount of money spent on vehicle repairs actually decreased during the same period of time. This is why the cost of repairs have not been included in the total costs for vehicle inspections. Obviously, very little improvement can be achieved by inspections unless the defects found in the vehicles are repaired. At least part of the improvements which result from inspections must be assumed to stem from repairs which otherwise would not have been carried out. The costs for such repairs should thus be included in the total costs for the inspections. But the experience in Sweden has shown that these costs were more than balanced by the savings in total repair costs because defects were observed and repaired at an earlier and less costly stage than before. It is in fact likely that the earlier repairs and lower repair costs are part of the explanation for the increased service life of the Swedish vehicles.

It should be noted that although the useful life varied a lot between the different makes of cars, the 50% increase was observed for all the makes. If this increase had not occurred, and the life expectancy of private cars had remained on the level in the early 1960s, an additional number of about 100 000 new cars per year would have been necessary in order to maintain the size of the Swedish car fleet. In monetary terms this means a saving of SEK 3 000 million in 1977, over 3 200 million in 1978 and over 4 000 million in 1979, when the average new car price had reached SEK 40 000. These savings have continued to increase. If the periodic vehicle inspections in Sweden can take the credit for only 10% of this effect, it alone is sufficient to again pay the costs of the inspections.

Benefits of other kinds

There are a number of other undisputable effects of the periodic vehicle inspections which cannot be quantified at all in monetary terms. One such effect is the reduced air pollution due
to the exhaust emission checking. Diesel smoke checking and CO-at-idle emission checking are included in the inspection program. It is easy to show statistical evidence of the improvements over the years, but stating the benefit to the society of the reduced pollution in monetary terms is not possible.

Even if the direct purpose of the periodic inspections is to ascertain that the vehicle owners fulfil their obligation to keep the vehicles in a satisfactory condition, there is another important indirect effect in the form of a very comprehensive supervision of the standards of repairs carried out in the garage trade.

According to studies made by the Swedish Motor Vehicle Inspection Company some 30% of the cars presented for annual inspection have been subject to some form of repairs within two weeks before the inspection. Furthermore, some 20% of the vehicles will be failed and have to be repaired and subsequently presented for new inspection (or scrapped). Most of the vehicles are repaired and reinspected within a month, and then passed. Some 6% of the vehicles are failed a second time.

During the course of one calendar year a total of over 3 million repairs, carried out either immediately before or as a result of the inspection, will be examined by the inspectors. This constitutes a very substantial quality control of the standards of repair work. It is quite obvious that it must have an important influence on the general standard of repairs in the garage trade and, at the same time, it gives the vehicle owner expert assistance in assessing if the repairs of his particular vehicle have given satisfactory results. Thus increased quality of repairs - better value for money - and improved consumer protection are also effects of the periodic vehicle inspections, although difficult to quantify.

A third effect is the pressure put on the vehicle manufacturers by the statistical reports on inspection results. Ever since the start in 1965 the Swedish Motor Vehicle Inspection Company has published annual statistical reports, now titled "Weak Points of Cars". These reports have always included a model by model account of the defects observed in different vehicles. Nowadays, also other countries with periodic vehicle inspections publish the results in a similar manner.

This kind of reports give the motor manufacturers a feed-back of information, which is not obtainable in any other way. There are quite a few examples to show that the publication of inspection results indicating inferior reliability or durability of a certain construction, has resulted in new designs with better performance and reduced maintenance and repair costs for the owners.

A fourth effect is also achieved through the statistical work, namely a feed-back to the regulation-making authorities. It is easy to analyse and follow up the effects of regulatory changes in Sweden. Thanks to the about 20 000 inspections per day and
the statistical processing resources a short period of time is often sufficient for conclusive evidence to be established. Furthermore, the staff of the inspection company constitutes a resource with a wide range of knowledge and experience of vehicle technology and the application of traffic legislation, a resource which is available to the regulation-making authorities in their development work.

Finally there is reason to believe that the annual visits to the inspection station and the forced interest in the condition of the own vehicle have given the vehicle owners more understanding of the need for regular maintenance. This effect is likely to be part of the reason for the increased service life of the vehicles. There are also indications that Swedish vehicle owners have developed a more conscious attitude towards vehicle safety and traffic safety questions. It is possible that part of the positive effects of the periodic inspections on the traffic safety can in fact be attributed to their impact on the vehicle owners/drivers. It should be noted that the owner/driver stays with the vehicle during the whole inspection, is a passenger during the test drive and is able to follow the inspector's work, to ask questions etc.

Total benefits of the periodic inspections in Sweden

When adding up the quantifiable benefits of periodic inspections, calculated for the year 1979, there is no doubt that they exceed the SEK 395 million total costs. The direct safety improvement and the fuel savings (excluding fuel tax) add up to about 600 million. But this is then supplemented by the unquantifiable effects:

- reduced air pollution
- longer vehicle service life
- improved quality of vehicles and repair work
- consumer protection
- more efficient regulation-making process
- more safety-conscious and careful vehicle owners.

Nobody is likely to deny that these effects exist, but neither can anyone state in monetary terms what the effects are worth, nor to what extent they are attributable to the inspections. We know that the interest nowadays is focussing more and more on the environment and the importance of reducing emissions from the vehicles has increased. We also know that the small costs for the emission checks included in the periodic inspections are repaid several times over simply by the side-effect in the form of fuel savings. But the value of reduced air pollution should be determined in relation to costs for restoring environmental values that have been lost through pollution - and the whole truth about these costs is not known yet.

Ideas for future developments

There is no doubt that the Swedish periodic vehicle inspections are cost-effective, the question is only how much so. Although
this is satisfying, we are working continuously on different projects intended to improve the inspection system. Recently we have made some studies intended to produce ideas for improving the cost-efficiency of the system. The studies are not finished, but some of the results already obtained indicate that improved cost-efficiency may be achieved if certain changes are made to the inspection system.

We believe that earlier periodic inspection of heavy trucks and trailers would constitute such a worth-while improvement. In Sweden the heaviest trucks and trailers come to the first periodic inspection after a rather long period of time, almost three years. This means e.g. that the median mileage for the trucks is about 120 000 km and 25 % of the trucks over 12 tons GVW have exceeded 200 000 km. The heaviest trailers (over 20 tons GVW) also have very high mileages. Thanks to the special taxation odometers fitted to trailers we know that about 10 % of these vehicles have covered 300 000 km or more before the first periodic inspection. Heavy trucks and trailers are also the vehicle categories which have the highest numbers of defects and the highest failure rate.

Most countries in Europe require the first periodic inspection to take place after only one year of use for trucks and trailers over 3.5 tons GVW. There is reason to believe that it would improve the cost-efficiency of the periodic inspections, if Sweden would adopt the same rules.

Another point of interest is the varying "needs" for inspection in relation to the age of the vehicle and the mileage. Most countries with periodic vehicle inspection have some sort of annual or bi-annual cycles after an initial period of one, two or three years. A few countries, like Japan, Singapore, South Korea and Spain, have varying intervals in the sense that up to a certain age of the vehicles inspection every two years is required, then annual inspection up to another age limit, after which inspection every six months is required. Clearly, the regularity is chosen for reasons of simplicity in administration. There is reason to believe that such varying intervals reflect the real "needs" for inspection in a better way than the constant one-year interval practiced in most countries. Our studies indicate that if optimum use of inspection resources and optimum cost-efficiency of inspection is to be achieved, the interval between inspections should be shortened as the vehicle grows older and accumulates more mileage. The Swedish administrative system with its fully computerized vehicle register makes it feasible to design an inspection system with continuously variable intervals, e.g. a period of 12 months to the next inspection for the five-year-olds cars, 11 months for the six-year-olds etc. It would even be possible to let the inspection result and/or the accumulated mileage determine the interval to the next inspection for each individual vehicle.

However, in order to design such a system we would need more information about the occurrence of defects and the time/mileage of use in defective condition etc between the inspections.
Also, the influence of vehicle safety defects in the road accidents in Sweden must be better known. At present the concept of varying inspection intervals is only an idea that we want to develop in order to evaluate what gains in inspection cost-efficiency it could yield.

Concluding comments

The periodic vehicle inspections in Sweden have proved to be cost-effective means for the improvement of traffic safety and the inspection company can look back on the past two decades with satisfaction. But it is more important to look forward. It is necessary to develop inspection methods which can cope with the vehicles of the future. The inspection methods must be developed parallel to the development of new requirements by the regulation-makers and the development of new technical systems by the motor industry. Examples at present are technical methods to check

- catalytic converters
- electronic control units for e.g. anti-lock braking systems
- windscreen deterioration (objectively).

Periodic inspection and maintenance should ensure that the improved standards as regards safety and emissions built into the new cars can be kept at a reasonable level during their whole service life.

If the Swedish periodic inspections are compared with their counterparts in other countries many similarities will be found, but also a few differences. There are a few factors which should be emphasized, the foremost of which is the relations to the public.

In order to exploit the full potential of vehicle inspections as a means to improve traffic safety, the public's acceptance and confidence must be ensured. In Sweden we have deliberately subdued all elements of supervision and enforcement, and instead underlined the service element in the inspections. Each customer is entitled to value for his money in the form of a quite comprehensive technical examination by a well-trained and qualified vehicle inspector. And the customer is not only permitted to stay with the vehicle during the inspection, he or she is in fact encouraged, almost required to do so, to speak to the inspector and learn as much as possible about the vehicle. Hints on service and maintenance etc outside the scope of the inspections are given freely by the inspectors.

The independent and impartial organization in the form of a separate company has of course helped in getting the public's confidence. Other factors of importance in this respect are the nation-wide uniformity of inspection methods and equipment as well as assessment criteria. Also the comprehensive training given to already qualified mechanics before they become vehicle inspectors plays a role in achieving this uniformity.
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COLLISIONS INVOLVING PASSENGER CARS WITH DRIVER SIDE AIR BAGS

A US-Swedish R&D-Project

by

David Romeo, Leif Svensson, Jan Thorson

Abstract

During 1983 and 1984 there were registered 273 motor vehicle related occupational injuries among employees at the Swedish Post Office. In 186 cases the injuries occurred while driving cars and trucks, the rest of the material, 87 cases occurred during loading and unloading.

In almost 1/3 of the 186 traffic injuries collisions involved an oncoming vehicle. Single vehicle events occurred in somewhat less than 1/5, rear collisions in 1/10 and "none specific events" in somewhat more than 1/3 of the material. Nine cases were jamming injuries, caused by sliding doors. Cars for urban postal transport have these doors.

Normally seat belts are not used extensively among occupational drivers. This is one reason for a development project for passive safety.

Our aim was, in this respect, to demonstrate the feasibility of a driver air bag retrofit system into Swedish Postal Opel Kadett.

This was accomplished by:

- installation of Romeo Kojyo air bag systems, suitably modified in postal vehicles, currently in service,
- acquiring field experience with the systems,
- subjecting vehicles to rough road testing and low speed barrier testing, and finally,
- crash testing two of the vehicles in full frontal barrier crashes at speeds of 40 and 50 kph.

All aspects of the project were successful.
COLLISIONS INVOLVING PASSENGER CARS WITH DRIVER SIDE AIR BAGS
A US-SWEDISH R&D-PROJECT

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COLLISIONS INVOLVING PASSENGER CARS WITH DRIVER SIDE AIR BAGS

A US-Swedish R&D-Project

Abstract

During 1983 and 1984 there were registered 273 motor vehicle related occupational injuries among employees at the Swedish Post Office. In 186 cases the injuries occurred while driving cars and trucks, the rest of the material, 87 cases occurred during loading and unloading.

In almost 1/3 of the 186 traffic injuries collisions involved an oncoming vehicle. Single vehicle events occurred in somewhat less than 1/3, rear collisions in 1/10 and "none specific events" in somewhat more than 1/3 of the material. Nine cases were jamming injuries, caused by sliding doors. Cars for urban postal transport have these doors.

Normally seat belts are not used extensively among occupational drivers. This is one reason for a development project for passive safety.

Our aim was, in this respect, to demonstrate the feasibility of a driver air bag retrofit system into Swedish Postal Opel Kadett.

This was accomplished by:
- installation of Romeo Kojyo air bag systems, suitably modified in postal vehicles, currently in service,
- acquiring field experience with the systems,
- subjecting vehicles to rough road testing and low speed barrier testing, and finally,
- crash testing two of the vehicles in full frontal barrier crashes at speeds of 40 and 50 Kph.

All aspects of the project were successful.
Background

In a recent pilot study concerning state employees at the end of the seventies, it was found that in 400 occupational accidents one was fatal, in 200 commuting accidents one was fatal, and in 700 cases of occupational disease none were fatal. Among all Swedish occupational accidents in 1983, 121 were fatal; 11 of these were occupational driver fatalities. In the figure below the relative distribution of these fatalities by injurious event is shown. The proportion of fatalities related to vehicle transport is predominant among all occupational accidents (35 %) and the risk is still more striking among occupational drivers (55 %). Other injurious events causing fatalities are persons falling or being hit by some object, for example a part of machinery. Figure 1.

Figure 1. Fatalities among occupational accidents 1983 according to type of injurious event. Relative distribution.
The Swedish Post Office

A special analysis of injuries in the Swedish Post Office is an illustration of the injury mechanisms to drivers of smaller motor vehicles. In table 1 the primary circumstances preceding the injuries are illustrated. Details of traffic injury cases on the sick list are shown in table 2.

Table 1. Circumstances preceding injuries which were related directly to car driving.

<table>
<thead>
<tr>
<th>Circumstances</th>
<th>1983</th>
<th>1984</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collision on meeting</td>
<td>35</td>
<td>21</td>
<td>56</td>
</tr>
<tr>
<td>Single vehicle accidents</td>
<td>23</td>
<td>21</td>
<td>44</td>
</tr>
<tr>
<td>Rear collisions</td>
<td>12</td>
<td>6</td>
<td>18</td>
</tr>
<tr>
<td>Collisions when starting from the road</td>
<td>2</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>Road crossing collisions</td>
<td>11</td>
<td>13</td>
<td>24</td>
</tr>
<tr>
<td>Collision with locomotive</td>
<td>1</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Collision when overtaking</td>
<td>-</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Collision with a moose</td>
<td>1</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Collision with a pole</td>
<td>-</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>10</td>
<td>12</td>
<td>22</td>
</tr>
<tr>
<td>Jamming by a movable door</td>
<td>-</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Other accident during transport</td>
<td>5</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>86</td>
<td>186</td>
</tr>
</tbody>
</table>

Comments: In 18 cases the injuries were caused by rear collisions. In 56 cases the injuries were caused by collisions between meeting vehicles. 44 cases were single vehicle accidents, i.e. collisions with more or less fixed objects and 24 cases were collisions with another vehicle in a crossing. Nine city postmen had suffered jamming injuries when driving with an open movable door: on hard breaking, the door latch had not been able to resist the deceleration forces and had jammed the driver. Doors are often involved in other injury types, e.g. strained muscles are easily caused by doors which have to be opened and closed several times a day.
Table 2. Direct causes of injuries to 62 persons among 186 vehicle-transport-injured post men, absent from work, or with long term effects after accidents during transport in 1983.

<table>
<thead>
<tr>
<th>Interior detail causing injury</th>
<th>Ordinary Passenger car</th>
<th>Country postman car</th>
<th>Town postman car</th>
<th>Standard distribution car</th>
<th>Truck</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Back support incl. head rest</td>
<td>1</td>
<td>2</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>4</td>
</tr>
<tr>
<td>Inner roof</td>
<td>-</td>
<td>2</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>Steering wheel</td>
<td>-</td>
<td>6</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>11</td>
</tr>
<tr>
<td>Window (windshield, side window)</td>
<td>-</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>-</td>
<td>11</td>
</tr>
<tr>
<td>Instrument panel</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Deformed front</td>
<td>-</td>
<td>5</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>Splinters of glass</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Door</td>
<td>-</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>-</td>
<td>6</td>
</tr>
<tr>
<td>Seat belt</td>
<td>2</td>
<td>5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>7</td>
</tr>
<tr>
<td>Pedal</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>Other detail</td>
<td>-</td>
<td>3</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>4</td>
</tr>
<tr>
<td>Unknown detail (for example unconsciousness)</td>
<td>-</td>
<td>5</td>
<td>1</td>
<td>2</td>
<td>-</td>
<td>8</td>
</tr>
<tr>
<td>No spec. detail (experienced as a sudden push)</td>
<td>-</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>5</td>
</tr>
</tbody>
</table>

Comments: The steering wheel and the windows predominate among details contributing to the injury. Seat belt use was infrequent; seat belts were, generally speaking, probably only used by a few if any and among those who were injured the use of the seat belt was probably still more unusual. However, if seat belts were used, they should have been effective in mitigating injuries to these occupational drivers.
Air Bags

If a passive approach to the problem of reducing collision injuries is implemented the main draw-back of manual seat belts - the insufficient use of them - will be eliminated. Earlier experience, e.g. (1-6) speaks in favour of air bags. We decided to study the feasibility of installing air bags in postal Opel Kadetts. Also the fact that small passenger cars were not used earlier for retrofit air bag installations gave it special interest. We used the Romeo Kojyo retrofit system which has been in use for a few years in the US police fleet field experiment (1-3).

Installation

Figure 2. Sketch of Sensor Locations.
Installation of the air bag system in the first two 1985 Opel Kadett vehicles was carried out at the Hedemora Bilteknik AB (HBAB) Facility, Hedemora, Sweden, during the last two weeks of November 1986 by Romeo Engineering, assisted by technicians at HBAB. A brief description of the system and its installation follows.

In the engine compartment, the system consists of two front crash sensors which are mounted in the crush zone of the vehicle, and a low level safing sensor located at the firewall. These are connected with a protected wiring harness which passes through the firewall and connects to a diagnostic unit which is mounted in the occupant compartment.

Initially, the crash sensors were located relatively far forward in the engine compartment. Figure 2 is a sketch which shows this location. This, as well as a location just aft of the shock towers, was evaluated in the sensor threshold barrier tests.

The diagnostic system is mounted under the instrument panel. In addition to connecting to the front sensors, it has wiring which leads to power and ground and a readiness indicator light. It goes up the steering column through a special coiled connector to a four spoke air bag steering wheel. The power wire is hooked to an ignition circuit in such a way that the air bag system is active only when the ignition is on.

The steering wheel, which is mounted using a hub fabricated to fit the column shaft, has two horn buttons mounted on the upper spokes. The air bag module is attached to the steering wheel using four allen head cap screws and consists of a gas generator, a neoprene coated nylon air bag, metal mounting components and a special reinforced cover assembly.

A knee bolster is a supplementary restraint for the lower part of the body. It is mounted over the lower part of the instrument panel on the driver’s side and consists of a 1 mm thick sheet metal, energy absorbing foam and a vinyl cover. The knee bar must be designed to fit each individual car. Materials were shipped to HBAB and the knee bars were designed, fitted and installed right at the facility.

**Test results**

Evaluation of the installed driver air bag systems was conducted through a series of tests: field experience, rough road tests, sensor threshold barrier tests, and air bag performance evaluation by frontal barrier crash tests.
Field experience

As part of the project, the two vehicles which received air bag systems in November were road tested under actual post office delivery route use during the period end of November, 1986 to end of March, 1987 a period of approximately four months. During this time, they each totalled a mileage of approximately 20,000 kilometers without any faults occurring in the system.

Rough road tests

In addition to normal usage of the vehicles, a short series of rough road tests was conducted. This consisted of driving the vehicle at increasing speeds from 20 km/hr to 50 km/hr over a curb whose height was 100 mm and at speeds of 30 and 40 km/hr over a curb whose height was 127 mm. These tests were conducted by the staff at HBAB and during the tests the gas generator circuit was replaced with a flash bulb such that any front sensor closures would fire the flash bulb rather than deploy the air bag.

No front sensor closures occurred in these tests. However, because the vehicles were not to be damaged (they would be used also in the high speed barrier tests), the curb tests were perhaps not severe enough to ensure that the sensor would not close in a curb test up to the limit of potential occupant injury. Nevertheless, these tests certainly added confidence to the belief that unwanted deployments due to rough driving would not occur in service.

Sensor threshold barrier tests

Adam Opel conducted four frontal barrier tests during February and March, 1987 in order to provide sensor closure data for the post office vehicle project. Tests at nominally 10, 12, and 20 km/hr were run 12 February and a test at 50 km/hr was run on 18 March. Four sensor accelerometer package locations were tested for and aft, left and right as shown in the sketch of Figure 2 and the photographs on Figure 3. Results of the threshold barrier tests are presented in table 3.
Table 3. Summary of the sensor closure results.

<table>
<thead>
<tr>
<th>TEST</th>
<th>SPEED km/hr</th>
<th>SENSOR CLOSURE, msec</th>
<th>Aft Left</th>
<th>Right</th>
<th>Left</th>
<th>Right</th>
</tr>
</thead>
<tbody>
<tr>
<td>476</td>
<td>11.7</td>
<td>No</td>
<td>40</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>477</td>
<td>9.8</td>
<td>No</td>
<td>47</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>480</td>
<td>19.8</td>
<td>21</td>
<td>25</td>
<td>23</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>481</td>
<td>49.8</td>
<td>9</td>
<td>9</td>
<td>11</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

Since it was believed prior to testing that sensor closure should not occur below 12 km/hr or 10 km/hr at the least, the first test was run at 12 km/hr to determine if sensor closure would occur.

The right front sensor closed at 40 msec indicating the air bag would deploy at this crash speed, approximately 7.5 mph. This was undesirable. However, it was felt we might be able to accept closure above 10 km/hr if necessary. The second test at 9.8 km/hr also resulted in sensor closure on the right side for the forward location, this time at 47 msec.

The next question was what the sensor closure times at 20 km/hr were, a threshold condition at which air bag deployment should occur. The third test produced acceptable sensor closure times for all four sensors ranging between 21 and 28 msec. The penalty of using the aft location; i.e., delay between front and rear closure time was only 2-3 msec.

Figure 3. Sensor and accelerometer package locations;
a: Left side. b: Right side.
Since a sensor closure time of equal to or less than 20 msec was desired for the 50 km/hr test condition, Adam Opel agreed to conduct one more test for us which they did on 18 March. This produced easily acceptable closure times at all locations and only 1-2 msec delay between front and aft locations. Therefore, the aft (just behind the shock towers) location was selected and used in the air bag performance crash tests conducted at Linköping, Sweden.

As a matter of interest, sensor closure time for the right front sensor location is shown plotted as a function of impact velocity in Figure 4.

Figure 4. Sensor closure vs speed. Opel Kadett, right front.
Crash tests

Two full frontal barrier crash tests were conducted at impact velocities of 40 km/hr and 50 km/hr on April 1 and 2, 1987 at the Swedish Road and Traffic Institute, Linköping, Sweden.

The first test was conducted at 1:00 p.m. on April 1 in front of approximately 40 observers, including the Institute, Insurance Company representatives, the Post Office Service and the press. The actual crash speed was 39.5 km/hr using an unbelted 50th percentile driver dummy (U.S. FMVSS 208 test set up). Excellent results were obtained.

Sensor closure time was approximately 12-14 msec. The dummy results were:

- Head Injury Criteria, HIC = 560
- Chest Resultant Accel. CR = 40 g
- Femur Left F₁ = 1,078 lbs.
- Femur Right Fᵊ = 704 lbs.

The second crash under the same test dummy set up conditions was run at 11:15 a.m. on April 2, 1987 at an actual impact speed of 48.9 km/hr. Again, the dummy results were excellent.

HIC = 688
CR = 48 g
F₁ = 1,738 lbs.
Fᵊ = 1,276 lbs.

Table 4. Summary including standard (United States Federal Motor Vehicle Safety Standard 208) tolerable limits.

<table>
<thead>
<tr>
<th>TEST</th>
<th>SPEED km/hr</th>
<th>HIC</th>
<th>CR g's</th>
<th>F₁ Pounds</th>
<th>Fᵊ Pounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>39.5</td>
<td>560</td>
<td>40</td>
<td>1,078</td>
<td>704</td>
</tr>
<tr>
<td>2</td>
<td>48.9</td>
<td>688</td>
<td>48</td>
<td>1,738</td>
<td>1,276</td>
</tr>
<tr>
<td>FMVSS 208</td>
<td>48.3</td>
<td>1,000</td>
<td>60</td>
<td>2,250</td>
<td>2,250</td>
</tr>
</tbody>
</table>

The conclusion based upon these results, is that the air bag system meets requirements of United States Federal Law for Passive Restraints.
Conclusions and recommendations

The project was conducted and completed essentially as proposed and within the budgeted time and cost allocations. The feasibility of installation of retrofit driver air bag systems into Opel Kadett postal vehicles was satisfactorily demonstrated. In fact, the systems easily met the United States Federal Motor Vehicle Safety Standards for automatic or passive restraints.

Based upon these results, continuance of the project through implementation of the system into fleet postal vehicles is recommended. It is our understanding that there are approximately 390 of these standard versions of this model in actual use (model years 1985, 1986 and 1987).

Extension of this project into the Volvo Taxi fleet in Sweden would require an initial project of approximately similar scope to that just conducted on the Opel Kadett. However, based upon the success of the Opel Kadett project, the cost of this engineering or demonstration phase could be reduced somewhat.

Unit costs for quantities of several hundred systems are difficult to predict accurately at this time, due to several factors. On the one hand, the weakness of the U.S. dollar against the Japanese yen and German mark have adversely affected components costs. On the other hand, continuance of this project may be able to take advantage of lower costs which should result since many of the components will be produced in high production volumes for introduction as original equipment in production automobiles.

The ability to take advantage of high volume production cost savings will depend to a large extent on the willingness of both component suppliers and automobile manufacturers to cooperate in these projects.

In summary: one year ago, the unit price of a retrofit system in the quantities we are discussing was approximately $900. Unit costs for the postal vehicle could now range from as much as $1,000 to $1,100 with little or no help from component suppliers or automobile manufacturers, down to as low as $700 to $800 if we are able to obtain good support from these same companies.
Acknowledgement

The authors acknowledge and give thanks to the following persons.

Olle Steen and his capable crew at HBAB;

Dieter Shaper of Adam Opel AG for his contribution regarding the low speed tests;

Thomas Turbell and his crew at the Swedish Road and Traffic Research Institute;

Charles Merlino of Merco;

Stefan Kittl of Romeo Engineering for contributions to installation of air bag systems.

References


CHILD RESTRAINTS IN EUROPE

by Thomas Turbell, M.Sc., Research Director, Swedish Road and Traffic Research Institute, Sweden

ABSTRACT

The present situation regarding the accidents to children in cars in Europe is presented and comparisons between different countries are discussed.

The historical evolution of child restraints is shown and the background to the European Regulation is given. The design of the ECE-regulation will be presented and statistics will be given about the present number and types of approvals. Problems with the use and interpretation of the regulation will be discussed and proposals for amendments will be put forward. Different types of restraint systems for handicapped children will be shown as well as other special systems that allows for 4 restrained children in a rear car seat with only 3 belts. The great success of the loan programme in Sweden where 90% of all newborn children leave the hospital in an infant seat that is supplied by the government will be described as well as the investigations on which effects this loan system will have on the future use of child restraints.

Different approaches to information activities in order to increase the usage rates will be presented.

The present situation regarding legislation on mandatory use of child restraint in some countries and especially in Sweden where there in 1988 will be a law requiring all car passengers in all seating positions to be restrained by either a seat belt or a special child restraint system will be discussed.
THE CHILD IN THE VOLVO CAR

Gerd Carlsson, Jan Holmgren and Hans Norin
Volvo Car Corporation

ABSTRACT

The objective of this report is to describe Volvo's development work in the field of child safety. Experience from car accidents involving children is used to describe different modes of travel for children of different age groups, the effectiveness of different child restraint systems and problems of misuse.

The problems of differences in the requirements of child safety legislation are discussed.

This experience combined with experience gained from laboratory tests, constitutes the basis for development work on child safety systems in Volvo cars.

Volvo's new child safety program covers all age groups of children and needs for different ways of travel.

VOLVO SAFETY DESIGN PHILOSOPHY

To Volvo safety has always meant safe transportation in a real traffic environment. Volvo Safety Design Philosophy can be illustrated by a circle as in Figure 1.
For many years the Volvo Traffic Accident Research Team has been extensively engaged in investigating accidents and increasing its know-how about the crashworthiness properties of complete vehicles and their various design systems, and about the various occupant injury mechanisms. This knowledge is used both for short-term and long-term feedback in the development of future vehicles.

This feedback is one important source of information for establishing the safety property requirements of a car. These requirements then provide the basis for design and development work.

**TRAFFIC ACCIDENT EXPERIENCE**

Experience gained from the Volvo accident material described below gives us knowledge of the way children travel in cars and injury risks for different modes of travel.

**Background Data**

Each year, Volvo compiles information on about 2,000 of the most serious road accidents in Sweden involving Volvo cars. The accident material is based on a repair cost criterion where all cars of a repair cost of 15,000 SEK or more are selected. In addition, in-depth studies are made of between 150 and 200 serious road accidents in which a Volvo car was involved as well as a number of special studies.

The accident study material for the years 1976-1986 covers approx. 1000 serious road accidents in which at least one child was an occupant of the car. The material involves Volvo cars of the 140/160, 240/260, 340/360 and 740/760 models.

**Mode of Travel**

There were a total of 1601 children involved in the accident material. In the case of 1463 children, it is known whether or not they were travelling restrained. Only these 1463 children are covered in the following analysis.

Figure 2 below shows how children split into different age groups have been travelling during 1976-1986.
<table>
<thead>
<tr>
<th>MODE OF TRAVEL</th>
<th>0-11 months</th>
<th>1-3 years</th>
<th>4-6 years</th>
<th>7-10 years</th>
<th>11-14 years</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>RH front seat-belted</td>
<td>2</td>
<td>5</td>
<td>14</td>
<td>115</td>
<td>136</td>
<td></td>
</tr>
<tr>
<td>RH front seat-unbelted</td>
<td></td>
<td></td>
<td>1</td>
<td>6</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Outboard rear seat-belted</td>
<td>7</td>
<td>34</td>
<td>46</td>
<td>69</td>
<td>156</td>
<td></td>
</tr>
<tr>
<td>Outboard rear seat-unbelted</td>
<td>41</td>
<td>108</td>
<td>170</td>
<td>213</td>
<td>532</td>
<td></td>
</tr>
<tr>
<td>Centre rear seat-belted</td>
<td>4</td>
<td>8</td>
<td>13</td>
<td>5</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Centre rear seat-unbelted</td>
<td>24</td>
<td>42</td>
<td>56</td>
<td>37</td>
<td>159</td>
<td></td>
</tr>
<tr>
<td>Child seat/Infant seat</td>
<td>10</td>
<td>82</td>
<td>5</td>
<td>97</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Booster cushion</td>
<td>22</td>
<td>51</td>
<td>36</td>
<td>109</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carrycot</td>
<td>28</td>
<td>6</td>
<td></td>
<td>34</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Luggage compartment - unrestrained</td>
<td>2</td>
<td>4</td>
<td>9</td>
<td>8</td>
<td>4</td>
<td>27</td>
</tr>
<tr>
<td>Other modes* - unrestrained</td>
<td>7</td>
<td>64</td>
<td>53</td>
<td>32</td>
<td>20</td>
<td>176</td>
</tr>
<tr>
<td>TOTAL</td>
<td>47</td>
<td>256</td>
<td>316</td>
<td>375</td>
<td>469</td>
<td>1463</td>
</tr>
</tbody>
</table>

*) Other modes of travel include lying or standing on the rear seat, sitting on the lap, sitting between occupants

Figure 2. Mode of travel for different age groups during 1976-1986. (Volvo Accident Material)
Comments. Of the children in the age group 0-11 months, 6 travelled in an infant seat and 4 in a child seat. All seats facing rearwards.

28 of the children between 0-11 months travelled in a carrycot. The reason for this is that up to 1984 it was recommended in Sweden that infants should travel in a carrycot. In 1984, however, infant seats were introduced in Sweden and today - 1987 - approx. 90% of the infants travel in infant seats.

Since only rear facing child seats are recommended in Sweden all except two seats in the accident material were facing rearwards.

In figure 3 the percentage of children in different age groups using some type of safety equipment is shown. In this report safety equipment is recognized as infant seats, child seats, booster cushions and seat belts.

![Graph](image)

**Figure 3.** Percentage of children in different age groups using some type of safety equipment 1976-1986 (Volvo Accident Material)

As we can see from figure 3, restraint use is highest amongst children from 0-1 years (53%) and for children from 1-3 years (46%).

Children between 4-10 years have the lowest restraint use (31%) while restraint use for the older children is 40%.

However, the restraint use for children in all age groups has increased rapidly from 1981 and onwards, as shown in figure 4.

Carlsson, Holmgren and Norin
As we can see from figure 4, the percentage of restrained children increased from 22% in 1976 to 72% in 1986.

The group of children that accounts for the growing restraint use mainly consists of children using booster cushions and seat belts. This primarily means children between 4-10 years, but to some extent also includes children between 1-3 years.

The increased restraint use amongst children from early 1980 can be explained by many factors. During the beginning of 1980s many campaigns were carried out in order to provide knowledge of the importance of using child safety equipment when travelling in cars. Some years later intensive campaigns dealing with the use of seat belt in the rear seat started.

In 1984 some county councils in Sweden started loaner programs of infant seats directed towards people with newborn babies. These loaner programs, which today cover all of Sweden, have meant that approx. 90% of all infants travel in an infant seat today. The infant seats have to a great extent replaced the carrycots as a way of travel for infants. In 1986 a law making rear seat belt use also compulsory came into force in Sweden. Though the law excluded children under the age of 15, it has probably had an effect on increasing public awareness of the need of being restrained when travelling in cars.

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Injuries to Children

Injury frequency. In this section the accident material described above is used to analyse the injury risk for restrained and unrestrained children. The injury risks for restrained and unrestrained children are compared. Furthermore, calculations of restraint effectiveness are made.

As mentioned earlier, restrained children are those who use a two/three-point seatbelt, a booster cushion or a rearward facing child seat. Unrestrained children are those who travel in another way, except for children travelling in a carrycot. These children (carrycot) are excluded from the comparisons in this section.

The restraint effectiveness (e) is defined as the injury rate reduction attributable to restraint use, given as a percentage of the injury rate without restraint:

\[
e = \frac{\text{injury rate, unrestrained} - \text{injury rate restrained}}{\text{injury rate, unrestrained}} \times 100
\]

We will first compare the injury rate for all restrained and all unrestrained children. The injury rates are given for three levels of AIS. Totally there are 528 restrained and 901 unrestrained children between 0 and 14 years of age.

<table>
<thead>
<tr>
<th>Restraint</th>
<th>AIS 1 %</th>
<th>AIS 2-3 %</th>
<th>AIS 4-6 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>25.9</td>
<td>4.4</td>
<td>0.8</td>
</tr>
<tr>
<td>No</td>
<td>30.9</td>
<td>8.3</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Restraint effectiveness 16% 47% 60%

Figure 5. Injury rate and restraint effectiveness at three AIS-levels. Restrained and unrestrained children in the age group 0-14 years.

We can see from figure 5 that there is a restraint effectiveness at all AIS-levels. A restraint effectiveness of 50% can be calculated for injuries of a severity level AIS 2-6.

We then divide the restraint group into three subgroups. These subgroups are seat belt, booster cushion and child seat according to the previous definition.
<table>
<thead>
<tr>
<th>Mode of travel</th>
<th>AIS 1 %</th>
<th>AIS 2-3 %</th>
<th>AIS 4-6 %</th>
<th>Total No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seat belt</td>
<td>29.8</td>
<td>5.3</td>
<td>1.2</td>
<td>322</td>
</tr>
<tr>
<td>Boosters</td>
<td>29.4</td>
<td>3.7</td>
<td>-</td>
<td>109</td>
</tr>
<tr>
<td>Child seat</td>
<td>9.3</td>
<td>1.0</td>
<td>-</td>
<td>97</td>
</tr>
<tr>
<td>Unrestrained</td>
<td>30.9</td>
<td>8.3</td>
<td>2.0</td>
<td>901</td>
</tr>
</tbody>
</table>

Figure 6. Injury rate for three types of restraints for children age group 0 to 14 years. Three AIS-levels.

From figure 6 we can see that the injury rate for children using rearward facing child seats is extremely low compared to other modes of travel. For children using child seats and for children using booster cushions there are no injuries more severe than AIS 3.

Injuries more severe than AIS 1 for children using child seat and booster cushion are described in the appendix.

When estimating the effectiveness of the different types of restraints, it is important that each restrained population (e.g. child seat user) does not differ too much from the unrestrained population in variables than can influence the injury rates.

There is a difference in age distribution between the groups of children presented.

To reduce the risk of drawing faulty conclusions we compare the effectiveness for seatbelt and for booster cushion only for children in the ages between 3 and 10 years and the effectiveness of rearward-facing child-seat in the age group 1 to 4 years.

<table>
<thead>
<tr>
<th>Mode of travel</th>
<th>AIS 1 %</th>
<th>AIS 2-3 %</th>
<th>AIS 4-6 %</th>
<th>Total No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seat belt</td>
<td>31.3</td>
<td>3.5</td>
<td>0.9</td>
<td>115</td>
</tr>
<tr>
<td>Boosters</td>
<td>31.1</td>
<td>3.9</td>
<td>-</td>
<td>103</td>
</tr>
<tr>
<td>Unrestrained</td>
<td>30.0</td>
<td>8.6</td>
<td>1.9</td>
<td>536</td>
</tr>
</tbody>
</table>

Figure 7. Injury rates for unrestrained children and children using seat belts or booster cushions in the age group 3 to 10 years. Three AIS-levels.

Carlsson, Holmgren and Norin
The injury rates for all children (0-14 years) (figure 5) and children in the age group 3 to 10 years (figure 7) do not differ much:

From the figures in table 7 we can calculate the effectiveness in reducing AIS 2-6 injuries for seat belts to 58% and for booster cushion to 63%.

<table>
<thead>
<tr>
<th>Mode of travel</th>
<th>Injury rate (%)</th>
<th>Total No.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AIS 1</td>
<td>AIS 2-3</td>
</tr>
<tr>
<td>Child seat</td>
<td>7.2</td>
<td>1.0</td>
</tr>
<tr>
<td>Unrestrained</td>
<td>26.8</td>
<td>10.6</td>
</tr>
</tbody>
</table>

Figure 8. Injury rates for children, 1 to 4 years of age, using a child seat or being unrestrained. Three AIS-levels.

If we compare children in the age group 1 to 4 years depending on whether they have travelled in a child seat or travelled unrestrained we can calculate a very high effectiveness for the child seat in reducing minor as well as severe injuries. The effectiveness in reducing AIS 2-6 injuries is about 90%.

Among the children who used a child seat there is only one injury more severe than minor (see case 1 in appendix).

Types of injury. In figure 9 the numbers of maximum AIS 2-6 injuries for each body region are presented for different types of restrained children and for unrestrained children.

<table>
<thead>
<tr>
<th>Mode of travel Body region</th>
<th>Seatbelt No. %</th>
<th>Cushion No. %</th>
<th>Childseat No. %</th>
<th>Unrestrained No. %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head, face</td>
<td>15  4.7</td>
<td>4  3.7</td>
<td>1  1.0</td>
<td>70  7.8</td>
</tr>
<tr>
<td>Neck</td>
<td>1   0.9</td>
<td>-</td>
<td>-</td>
<td>4    0.4</td>
</tr>
<tr>
<td>Neck frontal</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1    0.1</td>
</tr>
<tr>
<td>Chest</td>
<td>1   0.3</td>
<td>1  0.9</td>
<td>-</td>
<td>9    1.0</td>
</tr>
<tr>
<td>Abdomen</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>9    1.0</td>
</tr>
<tr>
<td>Pelvis</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3    0.3</td>
</tr>
<tr>
<td>Vertebral</td>
<td>1   0.3</td>
<td>-</td>
<td>-</td>
<td>1    0.1</td>
</tr>
<tr>
<td>Upper extr.</td>
<td>2   0.6</td>
<td>1  0.9</td>
<td>-</td>
<td>20   2.2</td>
</tr>
<tr>
<td>Lower extr.</td>
<td>2   0.6</td>
<td>1  0.9</td>
<td>-</td>
<td>17   1.9</td>
</tr>
</tbody>
</table>

N = 322 109 97 901

Figure 9. Injury rate (AIS 2-6) body region vs type of restraint and unrestrained children 0-14 years of age.

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The most common type of injury of this severity (AIS 2-6) for each group is the head injury.

Of the 97 children travelling in a rearward facing child seat, there was only one injury more severe than minor, an AIS 2 injury to the head which is described in the appendix (case 1).

The AIS 2-6-injuries sustained by children using a booster cushion are described in the appendix (cases 2-5).

For children in child seats and children using booster cushions none sustained neck- or abdominal injuries of level AIS 2-6. For belted children one neck injury case was reported. This case was a severe sideswipe accident with a heavy truck. The belted driver was killed. The 12-year old belted girl in the right rear seat sustained a compression fracture on one of the cervical vertebraes (AIS 2) and a minor bruise on the abdomen.

From these injury figures we can see that the risk of severe neck and abdominal injuries caused by belt use is very low.

Misuse

Misuse can be defined as partial misuse or gross misuse. Partial misuse means, for example, child not properly restrained, wrong size or age of child restraint too old. Gross misuse means for example incorrect mounting or no mounting of child restraint.

Some surveys (1) (2) have shown that a great percentage of child safety equipment is being misused. However, the consequences of misuse from the injury point of view are relatively unknown and depend on the type of system being used.

Child seats. According to accident data from the USA, a correctly used safety seat reduces the fatality risk by 71% while a partially misused seat reduces fatality risk by 44% (1).

To obtain information on misuse in the Volvo accident material some special questions are put concerning mounting of the seat and restraint of the child.

In short this material shows that most of the child seats were mounted correctly. In none of the cases was it indicated that the seat came loose from its attachments. Only in 2 cases was the child not properly restrained in the seat.

This indicates that the misuse frequency of rearward facing child seats is low. This is also confirmed by the high injury-reducing effectiveness (90% for AIS 2-6 injuries).

Booster cushions. In the 109 cases with booster cushions 105 children used the booster cushion together with a lap-shoulder belt, 4 children together with a lap belt. In some cases children used a booster cushion without being restrained in a seat belt. These children are considered as unrestrained in this report.

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From the accident material it has not been possible to draw any reliable conclusions about the mounting of the booster cushions.

The best method of measuring the misuse of booster cushions is probably to make on-the-road inspections of the mounting of the boosters. Such inspections have been made in Sweden and these indicate that approximately 40% of all booster cushions are misused in some way. This type of misuse is mainly partial misuse, where the safety belt is not properly attached to the seat belt guide on the cushion (2).

Although the partial misuse of booster cushions is relatively high, there is a clear effectiveness (68%) in reducing more severe injuries (AIS 2-6).

However, more information is needed about the extent to which the misuse influences the injury outcome.

TEST EXPERIENCE

Each year, Volvo performs about 1000 tests in the Crash Safety Centre. Out of these tests about 80 are fullscale tests, 400 are crash simulations on a Hyge sled and 500 are component tests. Both frontal, rear end, oblique, offset and lateral collisions are tested and simulated. When the development of a new part or an accessory is discussed, relevant crash tests in different cars are planned. It is mostly a question of crash simulations but as far as possible tests in ordinary fullscale collisions are made. For instance, when the new child safety programme was under development almost 300 tests were carried out in the different Volvo cars to make sure that the child seats would behave in a proper way according to our own requirements.

Test Methods

Almost every country in the world has its own national requirements concerning child safety. This creates problems for car manufacturers and others when developing and/or manufacturing child safety equipment intended for different countries. One example of this is that some countries do not permit the transport of children under a certain age in the front seat, even if they are properly secured in a child seat. This means that it is difficult to manufacture a rearward facing child seat as those seats are normally installed in the front seat, leaning against the dashboard.

In North America another problem arises with the rearward facing seat. When certifying a child seat according to the federal regulations, it is only permitted to use a standard bench and a safety belt. It is currently not permitted to use something to lean a child seat against, for instance a dashboard or a front passenger seat. Therefore it is not possible to get approval for a rearward facing toddler seat.

The Swedish authorities, however, encourage both producers and users of child safety equipment to transport children up to approximately 4 years in rearward facing devices.
A European regulation, ECE 44 (4) has been adopted by almost all the countries in Europe. Manufacturers of child restraints may choose whether they want to apply for the ECE 44 approval or the national approval in the relevant countries.

What ECE 44 is to Europe, FMVSS 213 (5) is to the USA. An overall comparison between the two requirements is made in figure 10. Some expressions have been used in that comparison which may be described as follows:

Classes
- the integrated class, in which the belts and the seat are completely integrated with the child restraint
- the non-integrated class, in which the adult belt is used to restrain the child

Categories
- the universal category, in which the device is connected to the lower seat belt anchorages
- the semi-universal category, in which an extra anchor-point is used
- the specific vehicle category, in which any type of attachment to the car can be used

It should be noted that FMVSS 213 requires a set of American p572c dummies, 6 months and 3 years old. The 6 month old dummy is uninstrumented while the 3 year old dummy has accelerometers in the head and in the chest.

ECE 44 requires another set of dummies called the TNO-dummies, 9 months, 3, 6 and 10 years old. They are all instrumented with an accelerometer in the chest.

Our experience is that there is a big difference between the two sets of dummies. The 3 year old TNO dummy is, for instance, more sensitive to submarining than is the 3 year old p572c dummy. The 10 year old TNO dummy moves in an unrealistic way. The chest seems to be very stiff which together with a weak 'lumbar spine' means that the dummy has a tendency to slip out of the shoulder belt very easily, i.e. jackknifing. This problem has also been mentioned in other reports, for instance in (3).

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Figure 10. A comparison between FMVSS 213 and ECE 44.

1) It is possible to make the test either in a fullscale crash test or in a special vehicle body on the test-trolley.

Even though we are convinced that a rearward facing child seat offers a better overall protection than does a forward facing one, we have designed the combined child seat to be used in both ways. The reasons for this are:

- Forward facing child seats are generally used in countries outside Scandinavia. With this seat, we want to give people an opportunity to try the rearward facing seat as it is "included in the price" when they purchase it as a forward facing seat.

- To raise the usage rate of child restraints for this age-group as the child seat is useful from infancy up to approximately 4 years of age.

We made some sled tests in complete car bodies with existing forward facing child seats before we started the development work on our new child safety programme. The seats were all approved according to different regulations, for instance ECE 44, FMVSS 213 and F.

Carlsson, Holmgren and Norin
No child seat fulfilled our own requirements as regards effect in the car. For instance, submarining occurred with some European child seats. With some American child seats the dummy displacement was so big that the head of the dummy hit the back of the front seats. The reason why these things happened will be discussed below.

One of the most important parameters in the matter of forward facing child seats is the way the seat is secured to the car. FMVSS/CMVSS 213 requires that the seat is secured to the car with the ordinary seat belts while ECE 44 gives the designers free hands to choose whether they want to use the ordinary seat belts or extra fittings.

It is easier to obtain good crash performance with two extra straps that are bolted at the ordinary lower belt fixation points. This is also the most common solution in Europe. There are two reasons for this:

- The designers can choose the location of the straps on the child seat. This is very important as the angle of the straps decides how swiftly the child seat is restrained during a frontal impact. The more upright the angle, the greater is the rotation of the straps before they start to restrain the child seat. This results in a longer displacement of the child, which means an increasing risk of head contact with the interior, especially in smaller cars.

- All cars are not equipped with safety belts in the rear seat.

Use of the ordinary seat belts, as in all American child seats, creates the problem of the difficulty in tensioning the belt across the child and the child seat itself. This means that it is much harder to devise a good "force taking" angle of the lap belt. As many child seats today are designed in accordance with the federal regulations, another problem arises, i.e. that neither ECE 44 nor FMVSS/CMVSS 213 requires a complete safety belt when the crash test is carried out. These regulations do not require the use of a safety belt with a lock and locking tongue which in turn influence the fitness and the behaviour of the child seat in a proper car. As not all cars are the same, one can find cars with very high locks (1.5-2 dm) as well as cars with very low ones. The high locks may mean that it is very difficult to install the child seat as the lock often is very stiff. During a crash, this may result in bending of the lock which may destroy it. Furthermore, the efficiency of the restraint may be lower since the belt tension is reduced. This may also mean that the child seat becomes unstable during normal driving conditions. The big advantage of securing the child seat with the seat belt is of course that it is easier to use.

As mentioned before, tests of certain European approved forward facing child seats resulted in submarining problems in frontal impacts. This is a problem that does not exist in either rearward facing child seats or in North American forward facing seats. The reason why it does not occur in rearward facing devices is obvious. In North American child seats the reason is to be found in the design of the harness.

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The ECE 44 regulation requires that if the child is secured by a 5-point harness, then the crotch strap or any other strap passing between the child's thighs must break or disconnect from its fitting at a static load of not more than 50 N. On the other hand, FMVSS/CMVSS 213 requires that the crotch strap shall be fixed and not give way under any circumstances. The reason why ECE 44 requires a releasable crotch strap is the belief that the crotch strap may result in crotch injuries. Our opinion however is that the fixed crotch strap is much better as it keeps the lap belts low down on the pelvis which means that the hips will not move forward and cause injury in the genital area.

We have mounted a high-speed camera during a couple of tests to see what really happens in that region. No problems occurred as the fixed crotch strap held down the lap belts over the hips. What may happen with the releasable crotch strap is that the shoulder belts will pull the lap belts upwards towards the stomach as the shoulder belts are connected with the lap belts. This means that the risk for abdominal injuries increases as submarining may occur. It is, however, possible to design a forward facing seat the "European way" without the submarining problems, which is what we have done. We believe, however, that the European system is rather sensitive to changes in crash-pulses, stiffness of the seat cushion etc. This means that a "European" forward facing child seat ought to be car-specific or semi-universal rather than for universal use.

This judgement is made with the North American and the British markets in mind as no information on crotch injuries is available from the accident statistics. The British regulation permits the use of the fixed crotch strap.

Conventional Infant Seats

It seems that almost all countries believe in rearward facing systems for infants. The conventional pattern for this system requires only the safety belt, lap belt or lap/shoulder belt to be secured in the car; see Figure 11.

Figure 11. A conventional infant seat

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This is of course very convenient when installing the child seat in the car, but the simple installation sometimes creates some disadvantages which cannot be neglected.

- The child seat becomes unstable, which can cause problems.

- If an accident should occur the safety belt will only absorb forces in one direction. This means that the infant seat will be well restrained during the beginning of a frontal impact. However, the safety belt cannot prevent the infant seat from rotating towards the seat back of the front/rear seat during the rebound of a frontal impact or during a rear end collision. This means that the infant's head will contact some part of the seat back. Even if the seat back is mostly made of soft material there is a chance that the child will hit some structural components in the seat back, the head restraints or, if it is an angled collision, the B-pillar. Furthermore, in a multiple collision the infant seat can move around in the compartment in an uncontrolled way.

These disadvantages were taken into account in the design of the new combined infant and child seat.

Test Results

A comparison of the injury criteria has been carried out between the rearward and forward facing installation of the combined child seat. The tests were carried out in a Volvo 480 car body on a Hyge sled, with a frontal impact at 30 mph. The crash pulse is shown in Figure 12.

![Figure 12: Sled acceleration pulse. Frontal crash simulation.](image)
Figure 13. The staple diagrams show the difference in injury criteria between the forward and rearward facing position. A 3 year old American p572c dummy and a 9 month old European dummy was used. The 3 year old dummy shows a 57% lower HIC-value and a 20% lower chest acceleration when sitting facing the rear. The 9 month old dummy shows a 36% lower chest acceleration when sitting facing the rear.

**DESIGN CONCEPT**

**Volvo's Combined Infant and Child Seat**

The child seat is intended for children weighing up to 18 kg, i.e. in the age-group from newborns up to approx. 4 years old. It is designed to give the child a high crash protection in all kinds of accidents.

The seat is approved according to ECE 44, FMVSS 213 and CMVSS 213. It is possible to place the child seat in the rear seat or in the front seat, facing both rearwards and forwards. We believe, however, that all children in this age group, as far as possible, should be transported in rearward facing child seats.
Figure 14. Rearward facing front seat. Infant and toddler position. The child seat is placed on the passenger front seat with its back leaning against the dashboard. It can be adjusted to the desired angle by sliding the front seat forwards or backwards. The child seat is secured by an extra strap together with the passenger safety belt.

Figure 15. Rearward facing, rear seat

Figure 16. Forward facing

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Figure 15 - The child seat is placed on the rear seat with its back leaning against the back of one of the front seats. It can be adjusted to the desired angle by sliding the front seat forwards or backwards. The child seat is secured by an extra strap around the head restraint of the front seat together with the passenger safety belt.

Figure 16 - The child seat is secured with the ordinary seat belts of the car, i.e. the lap/shoulder belt or the lap belt.

The installation of the child seat is very easy in both the rearward and forward facing positions.

A Half-integrated Child Seat

A new type of child seat which is the first step towards integrated child safety has been developed for children with a weight between 9 and 18 kg, i.e. in the age group of about 9 months to 4 years of age.

The child seat is installed on the rear of the front passenger seat and is intended for use in the Volvo 740/760 from model year 1985. This means that it is a car-specific child seat which can only be approved according to ECE 44.

The big advantage of the seat is that it can simply be folded out of the way when it is not in use. This means that it is possible to transport 5 adults without having the problem of removing the child seat.

Figure 17. The half-integrated child seat. The child is secured by the front seat passenger safety belt.

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Booster Cushion

When the child has grown out of the child seat, a booster cushion together with a lap/shoulder belt can be used. The booster cushion affords greater comfort for younger children when the seat belt is used and it eliminates the risk of submarining.

Figure 18. The booster cushion can be supported with a backrest. The backrest works as a head restraint when the child's head reaches above the edge of the seat back.

CONCLUSIONS

- Restraint use amongst children travelling in Volvo cars in Sweden has increased from 22% in 1976 to 72% in 1986. This is probably a result of intensive campaigns, the infant seat loan programme for newborn babies, the seat belt law for adults, increased public safety awareness.

- The effectiveness of all kinds of restraints for children (child seat, booster cushion, seat belt) is 16% for AIS 1 injuries, 47% for AIS 2-3 injuries and 60% for AIS 4-6 injuries.

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- The effectiveness in reducing AIS 2-6 injuries to children in the age group 3-10 years is 58% for seat belts and 63% for booster cushions.

- The most common type of injury for both restrained and unrestrained children is the head injury.

- Severe neck and abdominal injuries caused by booster cushion use or seat belt use are almost non-existent among children in Volvo's accident material.

- Misuse frequency of rearward facing child seats is low.

- Although misuse of booster cushions is relatively high (approx. 40%), there is a clear effectiveness in reducing more severe injuries.

- We find from accident studies that frontal collisions are the more frequent types of collisions and are usually more severe than rear end impacts.

This means that a rearward facing child seat offers better protection to the child, since the crash forces are spread over the back, neck and head of the child. A further advantage with the rearward facing seat is that the risk of submarining is almost negligible.

Volvo's accident research shows that the rearward facing child seat has a very high injury-reducing effectiveness - 90% for AIS 2-6 injuries.

Volvo's laboratory crash tests also shows that although results and behaviour are good with the new forward facing seat, they are even further improved with the rearward facing one.

- It exists many different regulations on child safety. A harmonisation of the requirements is necessary to encourage car manufacturers and others to increase the development of "international" child safety.

- If a crotch strap is used it shall be fixed (the North American way) and not release at a certain force (the European way). No crotch injuries has been found either in North America or in England.
APPENDIX

Case 1 (child seat)  The car was hit obliquely from behind by a truck. There was extensive deformation of the right rear end of the car. The belted female driver (injured AIS 1) and two occupants were travelling in the car. One of them was a 7 year old boy (injured AIS 2) who travelled unbelted in the left rear seat and the other was a 2 year old girl who travelled in a rearward facing child seat located in the right front seat. The girl in the child seat was improperly restrained and was thrown backwards in the car. She sustained a facial laceration (AIS 1) and concussion (AIS 2).

Case 2 (cushion)  The car was hit in the right side by another car. The deformation was 2 according to the VDI-scale. A belted female driver was travelling in the car (not injured) together with a 31 year old male (injured AIS 2) in the left rear seat with a 2 year old girl on his lap (injured AIS 1) and a 5 year old girl in the rear right seat using a booster cushion. She sustained an abrasion on the left eyebrow and on the chin (AIS 1) and concussion (AIS 2), probably caused by interaction with the adult rear seat occupant.

Case 3 (cushion)  The car skidded on a snowy road with the left side first into a big tree. The deformation was concentrated to the left side behind the B-pillar (VDI 3). A belted male driver was travelling in the car (uninjured), together with a 35 year old belted female right front seat passenger (uninjured), an 8 year old girl in the right rear seat using a booster cushion (injured AIS 1) and a 5 year old girl in the left rear seat also using a booster cushion. This girl sustained minor lacerations on the upper and lower extremities and a more severe concussion (AIS 3), probably caused by direct head impact to the tree.

Case 4 (cushion)  Another car was overtaking a lorry and caused a severe front end offset impact to the case vehicle. The deformation to the Volvo car was extensive and concentrated to the left side of the front (VDI b). The occupants of the car were a belted 27 year old female who was killed, a belted 38 year old male in the right front seat (injured AIS 3), an unbelted 32 year old female in the right rear seat (injured AIS 4) and a 6 year old boy using a booster cushion in the left rear seat. The boy sustained a fractured right forearm (AIS 2) and a fractured right lower leg (AIS 2).

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Case 5 (cushion)

The car skidded sideways and was hit in the right side by another car. The deformation was concentrated to the area of the right rear seat passenger (VDI 2). The occupants of the car were a belted 50 year old female driver (injured AIS 1), a belted 17 year old male front seat passenger (injured AIS 2) and a 6 year old girl using a booster cushion in the right rear seat. The girl's injuries were facial lacerations (AIS 1), a severe concussion (AIS 4) and right side rib fractures including lung contusion (AIS 3). The injuries were probably due to head impact with the right rear window frame and chest impact with the car side interior.
LIST OF REFERENCES


4. ECE Regulation 44.

5. FMVSS 213, Federal register and NHTSA FMVSS Docket; NHTSA, Washington, D.C.

Carlsson, Holmgren and Norin
SIDE COLLISIONS AND CRASHWORTHINESS

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John Lane in Australia in 1942 noted that aircrafts should be certified in two ways; they should be both airworthy and crashworthy, and so the term "crashworthiness" was born.

The crashworthiness of passenger cars in side collisions is one main theme of research and development since years. This paper reviews some characteristics of lateral collisions, methods of reconstruction and the state of the art of formulating appropriate regulations. Based on the available statistics, the magnitude of the problem is described. The important factors generating injuries in lateral impacts are analysed, f.i. direction of striking force, collision severity, mass ratio between striking object and struck car. The response of the car to lateral loading in real accidents as well as in reconstructions are compared. The occupant kinematics and the time histories of an impacted car and its side wall are examplified. In lateral collisions the intrusion and the transverse impact velocity of the impacted car compartment must be reduced. Different measures are mentioned, f.i. door structure strength, force distribution to the rigid parts of the A- and B-pillar and padding.

In the second part of the paper, test methods for side impact safety assessment are outlined. For a global approach a mobile deformable barrier as well as a special dummy suitable for side impacts are key elements in this respect.

The actual work for the Commission of the European Communities in Brussels as well as for the Economic Commission for Europe in Geneva is concentrating on the evaluation of a barrier proposed by the European Experimental Vehicles Committee (EEVC) and of the European Side Impact Dummy (EUROSID). The state of the art and the expected progress are pointed out. The importance of international harmonisation in this field is stressed.
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John Lane in Australia in 1942 noted that aircrafts should be certified in two ways: they should be both airworthy and crashworthy, and so the term "crashworthiness" was born (1).

The crashworthiness of passenger cars - and this presentation is restricted to this type of cars - in side collisions is of great importance for traffic safety. The frequency of side impact accidents comes second to the frequency of frontal impacts. Due to the improvements for the protection in frontal crashes, and due to the high rate of belt wearing in Europe the relative importance of the improvement of cars with respect to protection in side collisions is apparent: it is reported, that 21 to 31% of serious or fatal car accidents are side impact accidents (2).

This paper summarizes shortly the available accident statistics, describes the basic mechanics in side collisions and outlines the proposals for legislative standards. The presentation refers mainly to the situation in Europe.

1. ACCIDENT STATISTICS

Over the last years a lot of statistical analyses within different European countries as well as in USA has been published (3,4,5,6,7,8,9).

All these data cannot be reviewed in this presentation in detail. The impact direction of the struck car, the area of impact, the collision speed, the seating position of the passengers, the use or non use of seat belts and the mass of the striking vehicle combined with its front stiffness are the most important influencing parameters. From papers of Mackay (3) and Otte (5) the following characteristics are summarized:

1.1 Definition

A lateral collision is not easy to define, because a car may be struck on the side but the direction of the impact force may
result in an occupant trajectory which leads to contacts with forward structures. Conversely the impact on the car may be to the front section but the direction of the striking force may result in a contact of the occupant to the side of the vehicle (3). Some 66% of side impacts show damage to the side of the car plus lateral contacts of the occupants.

1.2 Direction of the striking force

It can be difficult to assess the direction accurately (3). Otte found that from 220 accidents about 53% of vehicles suffered rectangular impacts and about 55% oblique impacts (5).

1.3 Zone struck, striking objects and mass ratio

The position of the impact region of 224 struck cars is shown in Fig 1 (5).

![Diagram showing the position of the impact region of 224 laterally struck cars.]

Fig. 1: Position of the impact region of 224 laterally struck cars

For about 79% of the laterally struck vehicles the impact point was in the region of the passenger compartment. Vehicles constitute some three quarters of the striking objects in serious side impact cases. Mackay reported (3) that for car to car collisions with MAIS (maximum injury severity grade) above 3 for the median the striking vehicle is only some 10% heavier than the struck car, the 80th percentile has a ratio of 1.5 : 1.
1.4 Velocity change and intrusion

In Fig. 2 the cumulative frequency of collision speed of impacted and impacting vehicles is shown (5).

![Cumulative frequency of collision speed of impacted and impacting vehicles]

Fig. 2: Cumulative frequency of collision speed of impacted and impacting vehicles

For the impacted vehicles the 65th percentile shows a collision speed of about 40 km/h, for the impacting vehicles the speed is about 50 km/h. The deformation of the side structure of the struck car can be assessed in terms of external crush (i.e. the amount of relative inward motion of the external car surfaces) or of internal intrusion (the static reduction in the interior lateral dimension of the passenger compartment). Danner has published data about intrusion depth for different typical forms of deformation (8).

1.5 The Occupants

The injured body region of laterally impacted vehicle passengers is published by Otte (5) for 176 injured persons seating on the impact side and 147 injured persons seating on the opposite side (see Fig. 3).
In this analysis (5) only front-seat passengers were studied, 34% of them were protected by seat belts. For the nearside and offside occupants the head is injured in 44 to 50% of all injuries, thorax, abdomen and the pelvis region are more frequent injured for the nearside than for the opposite side occupant. No significant differences were seen for injuries to the cervical vertebrae, the upper and lower extremities. There is a general consensus in the literature that in very severe and fatal side impacts the head, chest and abdomen are injured for the nearside occupants at similar frequency levels (3). The injury causing parts of the struck car are shown in Fig. 4 (5).
Fig. 4: Injury-causing parts for laterally impacted passengers, differentiated by seating position on the impact side (all injuries 100%) and on opposite side (all injuries 100%)
For the occupants on the impact side 41% of all injuries are caused by the side door, for the occupants on the opposite side this percentage is only 16%, where the frequency of injuries caused by contact to windscreen and dashboard is for this group about 39%. Mackay discussed the matter of causes of injuries in detail in (3) and he summarizes, that for chest and abdominal injuries the door structure is very predominant for the struck side occupant. The causes for head injuries are described as somewhat diffuse. The side header is a frequent source but in higher energy collisions the striking object becomes dominant.

The protective effect of seat-belts in side collisions was analyzed by Otte (5). The effect is of course influenced by the impact angle. In an oblique impact more than two thirds of the belt-wearing passengers on the impact side remained free of injury in his sample, but only one third in a rectangular impact direction. For passengers seated opposite the impact side, the protective effect of the belt was evident in all cases.

2. MECHANICS OF SIDE COLLISIONS AND COUNTERMEASURES

2.1 Mechanics

In the following the mechanics of a side collision are described in more detail (see Fig. 5), (10).

![Diagram of side collision](image)

impact speed: 50 km/h

collision angle: 90° left

Fig. 5: Test set-up for a side collision
Let us consider a case of a side collision (10,11,12) based on the parameters specified in some drafts for compulsory side collision tests: impact velocity: 50 km/h, collision angle: 90°, collision: left side of a stationary target car (see chapter 3.1).

When the impacting car hits the side of the stationary car, the structures of both cars suffer deformations. The "soft" side, allowing deformations of maximally 10 to 15 cm, will suffer deformations right away, herewith the forces developed and transmitted to the target car do not amount to much. When the occupant compartment of the target car then begins to deform, the impacting car suffers deformations as well. In this phase of deformation, the backing forces of the deformed body structures of both cars effect a change in the direction of the movement of both cars. The movement of the impacting car is decelerated directly from the time of contact whereas the hit car continues remaining in its position for a relatively long time period (about 15 ms), see Fig. 6, (10).

![Diagram](image)

Fig. 6: Laws of velocities versus time

After about 80 ms both cars will have gained about the same speed. The phase of deformation has thus come to an end and the
phase of elastic recovery begins, amounting to about 15% of the deformation as a whole.

A representation of the paths of both cars indicates that the maximum depth of deformation has been reached relatively early, thereafter a definite change in position of the target car takes place. After about 60 ms. The occupants, not being tightly fastened to the car in their compartment, are thus hit in the impact - though not right away, but with a certain time delay. Let us now consider the behavior of the side door in addition to the velocities of both cars. It can be seen (see Fig. 7), as said before, that a few milliseconds after the first contact the impacting car deforms the wall of the impacted car (10).

![Diagram showing the velocities of impacted and impacting car, side wall and dummy chest](image)

**Fig. 7:** Time histories of impacted and impacting car, side wall and dummy chest
In our own research projects (10) with the VW Golf the wall reaches a maximum value of about 38 km/h about 25 ms after impact. At that moment the chest of the dummy is hit. The velocity of the door drops to less than 20 km/h in the next 10 ms due to the mass of the hit dummy. After that, door and dummy are exposed to an acceleration of about 45 g. The inside of the intruding door hits the dummy after a way of about 12 cm is passed.

At the moment when wall and chest have the same velocity the displacement of the impacted vehicle is rather low in relation to the ground. This implies that the impact on the dummy is more or less over before the hit car changes its position (see next fig. 8).
Fig. 8: Acceleration, velocity and displacement of struck vehicle, its door and dummy chest with Golf II
Because of reaching the end of the deformation capacity of
the door and due to the higher velocity of the bullet car
(relative to the target car) at this moment the chest accelera-
tion of the manikin is still increasing, whereas the velocities
of the door and the bullet car drop in parallel. The maximum
velocity of the dummy chest is reached when the velocities of
both cars are the same, about 75 ms after the crash starts.

It is still an open question which factor of the above men-
tioned parameters is responsible for producing the injuries in
side collisions, that means which parameter has to be conside-
red as injury criteria.¹

Mass differences between both cars affect - within certain li-
mits - the occupant impact severity only slightly. This is cau-
sed by the fact that the energy needed for intruding the door
does not depend on different masses of the colliding car. The
consequence of this fact is that Δv of the struck car is not
the only parameter which represents the impact severity in side
collisions in contrast to frontal collisions. Experimental work
within the Joint Biomechanical Research Programme (KOB) has
confirmed these results (13). In this context it has to be no-
ted that heavier cars are in general stiffer than lighter cars,
therefore mass and front stiffness of the striking car are
mostly combined.

2.2 Countermeasures

The traditional methods of minimising occupant injury have been
to stiffen the door and provide padding. Hobbs (12) reported
that full scale tests have suggested that padding is more ef-
effective than structural stiffening. The most important changes
which can be made are to reduce the initial impulse on the oc-
cupant (by incorporating padding) and to increase the time over
which the change of velocity occurs. To maximize this time, it
is desirable to start the occupant moving as early as possible
in the impact. Although increasing the stiffness will gain ti-
me, too stiff a structure can delay the time at which the door
padding makes contact and starts to accelerate the occupant.
Simulation suggest that there is an optimum stiffness for any
particular set of circumstances. Excessive stiffness above this
optimum can actually increase injuries. This is also described
by Hardy (14). Results of computer simulation reported by Hobbs
(12) show that variation of model parameters does not show any
simple relationship between the above described parameters of
the mechanics of side impact and the injuries. Optimisation of
countermeasures must be based on the knowledge of the injury

¹The terminology used was developed by Aldman, see
Proceedings of the Symposium: Biomechanics of impacts in road
accidents, Brussels, 1983
criteria. Using different parameters like f.i. thorax compression, the Viscous Tolerance Criterion or the Thoracic Trauma Index [see (12)] different results for the optimum protection will result. But some general principles are mentioned by Hobbs (12) and Hardy (14):

- increased structural stiffness would be beneficial up to a maximum of about 2.5 times the stiffness of current vehicles

- provided that there is some padding to reduce peak forces, it would be desirable to minimise the gap between the occupant and the door, the padding should therefore be as thick as possible

- reducing the stiffness of the bullet car's front should have a big effect on reducing injury levels.

3. PROPOSALS FOR A SAFETY STANDARD

To improve the protection in side collisions the development and introduction of new car structures by the car industry based on modern regulations in this field are necessary. One of the conclusions of the EEC Symposium on the European Automobile in 1975 was that the correct approach to future legislation is to develop techniques which actually specify the forces and accelerations on a human substitute (3). In legislation, the global assessment of the protection characteristics of cars should be based on performance criteria (16).

3.1 EEVC proposal concerning the mobile deformable barrier

At the ninth ESV conference 1982 in Kyoto the European Experimental Vehicles Committee (EEVC) published a report: Structures - Improved side impact protection in Europe (2). At that time the governments of Sweden, United Kingdom, France, Italy, Netherlands and the Federal Republic of Germany were joining this committee. The Commission of the European Communities (EEC) participates in the work of EEVC as observer.

These members of EEVC considered that full scale tests were preferable to component tests in order to be the basis of future regulation concerning protection in side impact. Therefore a whole vehicle impact test was proposed. In order to be independent of the characteristics of the impacting car, the use of a mobile deformable barrier was recommended. Comparing the exi-

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2The definitions used in this chapter concerning full scale-, subsystem- and component testing are according to the ISO specifications (15).
In testing different barriers it was noted that the ground clearance and the force/total deflection law were the most notable differences. EEVC proposed therefore a new barrier, the characteristics are given in the literature (2).

The proposed side impact test with this barrier is also described in (2): The trajectory of the mobile impactor will be perpendicular to the stationary tested car and the impact speed will be 50 km/h. The performance of the test will be noted from a special side impact dummy located in the front seat on the impact side.

During the last five years a lot of tests using this proposed procedure were conducted in several European laboratories (see for example (17)). A reconfirmation of the barrier specifications was published recently by EEVC at the 11. ESV conference (18). Concerning the geometrical specifications the difficult problem of appropriate ground clearance was tackled. The low value of 250 mm was proposed 5 years ago in order to anticipate the evolution of car front structures design. In car-to-car tests of the most recent cars, however, the striking car over-rides the door sill, even in a diving braking position, this holds not true for tests with the deformable barrier, where the door sill is clearly involved in the energy dissipation and deformation. It is reported by Hobbs (12), that increasing the ground clearance to 300 mm - the value, originally proposed by the European car industry (CCMC) - would also raise the upper edge and then load the side of the struck car at a level which may be clearly higher than what occurs in car-to-car accidents. Our own projects do not confirm this (17).

The second characteristic reviewed are the force deflection specifications. The front face is built in Europe with different materials, honey comb and polyurethane foam. Concerning the foam a more or less important peak escaping from the corridor occurs at the beginning of the deformation. The next fig. 9 shows a typical force deflection curve in a frontal impact test of the barrier.
It is argued that the injury parameters depend mainly on the behavior of the barrier during its second half of deformation, that means that the corridor specifications would apply only to deformations greater than 15 cm.

3.2 EUROSID

From 1978 to 1982 the Commission of the European Communities promoted biomechanical research in Europe by sponsoring a coherent program of individual projects. In extensive studies three side impact dummies were tested. As a result, a unified European dummy was developed, called EUROSID (fig. 10).
This dummy consists of a pelvis from INRETS (France), an abdomen from TNO (Netherlands), a thorax and shoulders from TRRL (United Kingdom) and a neck from APR (France). The remaining components are from Hybrid II or Hybrid III. The objective behind the design of this dummy is to produce a practicable but realistic dummy which records critical levels of impact for injury to the pelvis, abdomen, thorax and head in lateral impacts. Within an EEC contract an extensive validation testing of EUROSID has taken place. In a seminar in Brussels in December 1986 the results were presented (16). EUROSID has shown to be at a very satisfactory state of development. The EEVC, which has been responsible for this dummy for years, has decided that the dummy in its present form is ready to be evaluated at laboratories and testing institutions around the world. Few changes in detail may be necessary after the tests have been carried out. The EEVC will continue its work until the end of this year, particularly in suggesting appropriate injury criteria.
and protection criteria values and evaluating possible design adjustments. As preliminary values the following tolerance levels (19) are considered: Head: HIC [1000], chest: deflection max [40-45 mm], abdomen: no switch contact corresponding to a force [4500 N], pelvis: force pubic symphysis and iliac wing [10 kN]. Other criteria, specially for the chest like the Viscous Tolerance Criterion and the so-called Thorax Trauma Index (TTI) can also be measured by EUROSID (12). For full scale tests with the EUROSID see (20). A consortium of three companies was set up 1986 to produce the dummy. EUROSID and its spare parts are marketed by TNO, Netherlands.

3.3 ECE and EEC

Side impact protection is an area which is not covered by any set-up of European requirements right now. No prescriptions exist for a dynamic test procedure. The Economic Commission for Europe (ECE) in Geneva has worked on a regulation for a lateral collision since years. Within Working Party 29 the Group of Rapporteurs on Crashworthiness has drafted a first regulation in December 1984. This regulation (TRANS/SC1/WP29/GRCS/ R.58) was based on the EEVC proposal mentioned above (21). Based on this ECE draft a proposal for a directive (22) for the European Economic Commission (EEC) in Brussels was drafted by the ad hoc group "Evolution of Regulations-Global Approach-Passive Safety" (ERGA). The comprehensive document ERGA S/65 introduced also the EEVC proposal concerning a side collision test. Some questions are still unsolved, among them the difficult matter of the ground clearance of the mobile deformable barrier. Even within the car industry opinions differ about the appropriate value (250 mm or 300 mm). The EEVC has agreed to provide the work of EEC/ERGA ad hoc group with further relevant information like the description of the EUROSID, the drawings, the calibration-, certification- and seating procedure as well as performance criteria. We hope to finish this work till the end of this year.

3.4 International Harmonization

Efforts in Europe and the USA have led to a separate development of homologation test procedures. A comparison of the American procedure proposed by the National Highway Traffic Safety Administration (NHTSA) and the EEC proposal is listed in the next table (23).
### Table: Comparison of the NHTSA and EEC test procedures from [23]

<table>
<thead>
<tr>
<th>PROCEDURE</th>
<th>NHTSA</th>
<th>EEC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TEST CONFIGURATION</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>impact speed</td>
<td>53.9 km/h (32.9 mph)</td>
<td>50 km/h</td>
</tr>
<tr>
<td>impact centre</td>
<td>left side barrier</td>
<td>symmetrical plane of barrier passes</td>
</tr>
<tr>
<td></td>
<td>front 940 mm (37&quot;)</td>
<td>through R-point</td>
</tr>
<tr>
<td>collision angle</td>
<td>90°</td>
<td>90°</td>
</tr>
<tr>
<td>crabbed angle</td>
<td>27°</td>
<td>0°</td>
</tr>
<tr>
<td>barrier braking</td>
<td>after 200 ms</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- *)</td>
</tr>
<tr>
<td><strong>VEHICLE</strong></td>
<td></td>
<td></td>
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<tr>
<td>front seat position</td>
<td>midpoint</td>
<td>50 mm forward of rearmost position</td>
</tr>
<tr>
<td>front seat back angle</td>
<td>manufacturer's stated nominal design position</td>
<td>25° rear or manufacturer's stated nominal design position</td>
</tr>
<tr>
<td>fuel tank</td>
<td>filled up to 93% capacity</td>
<td>filled up to 90% capacity</td>
</tr>
<tr>
<td><strong>BARRIER</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>weight</td>
<td>1338 kg (2950 lbs)</td>
<td>950 kg</td>
</tr>
<tr>
<td>front ground clearance</td>
<td>275 mm (11&quot;)</td>
<td>250 mm</td>
</tr>
<tr>
<td>front height</td>
<td>550 mm (22&quot;)</td>
<td>500 mm</td>
</tr>
<tr>
<td>front width</td>
<td>1650 mm (66&quot;)</td>
<td>1500 mm free, according to specifications</td>
</tr>
<tr>
<td>front material</td>
<td>aluminium honeycomb</td>
<td>(see (2))</td>
</tr>
<tr>
<td><strong>DUMMY</strong></td>
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<td></td>
</tr>
<tr>
<td>type</td>
<td>SID</td>
<td>EUROSID</td>
</tr>
<tr>
<td>number</td>
<td>driver + rear left passenger</td>
<td>driver</td>
</tr>
<tr>
<td>configuration</td>
<td>50th percentile male</td>
<td>50th percentile male</td>
</tr>
<tr>
<td>detail</td>
<td>no arms; increased chest mass</td>
<td>male</td>
</tr>
</tbody>
</table>

*) There is no definition in the EEC test procedure.
The American proposal not only differs with respect to the design of the test tool (mass, stiffness, ground clearance, impact point and width of the barrier front), but it also considers the velocity of the struck vehicle during the collision by choosing a crabbed angle of 27°. Furthermore NHTSA has developed another so-called Side Impact Dummy (SID). Within the scientific community the specifications of the EUROSID seem more human-like than those of the SID.

The governments of the European Communities have several times underlined the necessity of a worldwide international harmonization. Cars from different countries are sold all over the world, the phenomena of side collision casualties is a major concern for all industrialized countries and the tolerances of the human being as far as biokinetics of impacts are concerned are the same. At a public meeting of NHTSA in May 1986 as well as at the last ESV-conference the need for international harmonization was firmly expressed. In May 1987 NHTSA announced a notice of proposed rule making for the USA within this year. It is still not possible to estimate whether a common approach between Europe and the USA can be realized, but it is realistic to assume that different organizations like the Motor Vehicle Manufacturers Association (MVMA) and the car industry in Europe (CCMC) as well as others will submit a lot of remarks and comments on the USA-proposal for a side impact standard. According to the normal legislation procedure in the USA the administration of the department of transportation will respond to all these remarks. Therefore it is premature to anticipate the final US-decision. Within the EEC the above mentioned ERGA group is planning to present their final draft to the Commission at the end of this year. According to the European administration procedures in Brussels, again it is not possible yet to prognosticate the final directive. Concerning the further progress of the consideration in the ECE in Geneva it was decided in May 1987 to start again with the work on an ECE regulation after the ERGA group has finalized the draft of a side impact directive for the European Communities.

4. CONCLUSION

The protection of vehicle occupants in side collisions is an important issue. Due to the improvements of protection in frontal collisions the relative importance of side protection is increased.

A huge amount of research was conducted in the past ten years. The Commission of the European Communities has sponsored to a great extent research for the development of the barrier and has spent more than a million of ECUs only for the development of the side impact dummy EUROSID. Governments, research institutes and the car industry have invested great efforts in research and development activities concerning side impact protection.
We are now at a point where these scientific results are passed to legislation. Proposals for legal provisions are in progress at the Economic Commission for Europe of the UN, at the Commission of the European Communities as well as in the USA. At several occasions the necessity of harmonising these regulatory activities was stressed. It is important that no new barriers between Europe and the main trading partners in USA and in Japan are erected. The biomechanical resistance to impacts from road accidents is the same everywhere. So this global problem of protection in side collisions asks for a global technological answer.
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