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

- Markings, Signs and Signals
- Vehicles
Proceedings of the Conference
*Road Safety in Europe*
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– Markings, Signs and Signals
– Vehicles
Papers presented at the seminar were as follows:

M1 Chevron Trial (Helliar-Symons, R);
Visual Guidance in Road Work Zones (Aulbach, J);
Restructuring of Town Entrances on Roads Classified as Major (Steinbrecher, J);
Right Turns on Road by a Constant "Green Arrow Sign" (Krause, K);
Markings – An Important Visual Guidance System in Europe (Schoenborn, H D);
Traffic Safety Related to Types of Road and Traffic Signals (Jamroz, K and Michalski, L);
Route Choice Behavioural Models Analysis of a Route Guidance System for a Congested Urban Area (Carrese, S, Fusco, G and Gori, S);
Development of Checking System of Guiding Road Signs Using Digital Road Map Data Base (Seo, T, Sakai, Y and Hirai, S);
Car Characteristics and Safety (Fontaine, H);
Motor Vehicle Inspection – Its Importance for Road Safety (Fosser, S);
Stability of Four-wheel Drive Motor Vehicles of Categories M1 and N1 (Davidov, A D, Nikulnikov, E N and Salnikov, V I);
Vehicle Design for Secondary Safety (Thomas, P, Bradford, M and Ward, E);
Vehicle Design for Primary Safety (Galer, M);
Effectiveness of an Active Steering Wheel in Critical Driving Situations – A Proving Ground Experiment (Schumann, J and Naab, K);
Role of Car Size and Aggressivity in Relative Collision Safety (Wood, D P and Mooney, S);
Transport of Dangerous Goods (Joergensen, N O);
Transport of Dangerous Goods – A Risk Management Model (Brockhoff, L and Joergensen, N O).

Keywords:
PREFACE

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

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

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

Linköping, November 1992

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Vehicle Design for Primary Safety
Margaret Galer

Effectiveness of an Active Steering Wheel in Critical Driving Situations - A Proving Ground Experiment
Josef Schumann and Karl Naab

Role of Car Size and Aggressivity in Relative Collision Safety
D P Wood and S Mooney

Transport of Dangerous Goods
Niels O Jorgensen

Transport of Dangerous Goods - A Risk Management Model
Lars Brockhoff and Niels O Jorgensen

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WEDNESDAY SEPTEMBER 30

OPENING

11.00 - 12.00 (11 AM - 12 AM)

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

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

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

SESSION I (COMMON) EUROPEAN PERSPECTIVE

14.00 - 16.00 (2 PM - 4 PM)

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

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

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

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

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

Safety of City-Cars, Conflict between Ecology, Economy, Road Traffic Benefits and Safety
Hermann Appel, Berlin Technical University, Germany
WEDNESDAY SEPTEMBER 30

WORKSHOP

ROADSIDE SAFETY FEATURES

18.00 - 21.00 (6 PM - 9 PM)

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

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

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

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

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

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

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

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

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

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

Panel Discussion

VTI RAPPORT 380A
THURSDAY OCTOBER 1

SESSION II A - SAFETY IN SOME EUROPEAN COUNTRIES

9.00 - 12.00 (9 AM - 12 AM)

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

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

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

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

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

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

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

Comparison of the Problems of Austrian and Hungarian Road Users
Werner Klemenjak, Austrian Road Safety Board, Austria
THURSDAY OCTOBER 1

SESSION III A - ELDERLY ROAD USERS

9.00 - 12.00 (9 AM - 12 AM)

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

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

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

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

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

Personal Factors of Drivers' Self-Criticism
Tadeusz Rotter, Jagiellonian University, Poland
THURSDAY OCTOBER 1

SESSION II B - SAFETY & TRAFFIC MANAGEMENT

13.00 - 17.00 (1 PM - 5 PM)

Chairman: Sven Krarup Nielsen, Road Directorate, Denmark

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

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

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

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

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

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

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

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

Monitoring Traffic Enforcement Effectiveness on a National Scale
David M Zaidel, Irit Hocherman and Alfred Shalom Hakkert, Technion-Israel Institute of
Technology, Israel

VTI RAPPORT 380A
THURSDAY OCTOBER 1
SESSION III B - VULNERABLE ROAD USERS
13.00 - 17.00 (1 PM - 5 PM)

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

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

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

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

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

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

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

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

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

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

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

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

SESSION IV - MARKINGS, SIGNS AND SIGNALS

9.00 - 12.00 (9 AM - 12 AM)

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

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

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

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

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

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

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

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

Development of Checking System of Guiding Road Signs Using Digital
Road Map Data Base
Masaharu Kawashima, Youichi Sakai and Setsuo Hirai, Ministry of Construction, Japan
FRIDAY OCTOBER 2

SESSION V - VEHICLES

9.00 - 12.00 (9 AM - 12 AM)

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

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

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

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

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

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

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

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

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

CLOSING REMARKS
Mr Georges Dobias, Director General, INRETS, France, President of FERSI
A'Nuaimi S Bin Mohammed
Al Barawani M Bin Amor
Al Manthari T Bin M
Albus Christoph
Andrew Evans
Appel Herman
Asp Kenneth
Assaïlly Jean-Pascal
Assum Terje
Aulbach Johannes
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Helliar-Symons Robin
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The M1 Chevron Trial

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THE M1 CHEVRON TRIAL

Abstract of a proposed paper for the 1992 "Road Safety in Europe" Conference

by

Robin Helliar-Symons

A paper is proposed which will summarise the results of the first UK trials of Chevron markings on the M1 motorway.

The markings, which are inverted "V"s painted on the carriageway, are designed to assist drivers in choosing a safer following distance. They were laid at 40 metre intervals on two stretches of the M1 (one of 5 km and one of 4 km). Roadside signs advised drivers to follow with two Chevrons between themselves and the vehicle ahead. The measure was devised and first used in France.

Assessment of the effectiveness of the markings has been by two means: direct measurement of vehicle speeds and time spacings, and questionnaire interview surveys. The proportions of vehicles travelling at less then one second and at less than two seconds were recorded at three measurement points: "upstream" from the markings (to provide "Control" data), within the marked length and "downstream". The changes in these proportions were examined in each "After" measurement period (one week, one month, three months and six months) and tested for statistical significance. Vehicle speeds were also recorded and analysed, although the measure was not expected to have a particular influence on speeds.

Questionnaire surveys were conducted at the first motorway service area "downstream" from each trial site. At the initial site (near Leicester) surveys were made at one week and six months after the markings were laid. At the Northants site, they were only made in the first week after. Members of the public were asked if they had noticed, understood, tried to use and had any difficulty in using the markings.

Summaries of both the directly measured and questionnaire data would be presented, together with a description of the trial and, if available, the factors which led to the Department of Transport's decision on the future use of the Chevrons.

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VTI RAPPORT 380A
1. INTRODUCTION

When motorways were first introduced in Britain in the 1960s, we were able to learn from the experience of other countries and, through the design and high standard of civil engineering, build them to operate as safely as possible. Accident rates on motorways have always been very low, but public attention is drawn to occasional large multi-vehicle accidents and there is always pressure to look for safety improvements.

On British motorways, there are about 2,000 injury accidents per year involving nose-to-tail collisions. These represent an estimated cost to the community of £64 million per year (at 1990 prices). If drivers could be encouraged to adopt longer following distances, then it might be possible to reduce this accident toll.

In an attempt to achieve an improvement in drivers' following behaviour, markings were devised and first used in France which comprised arrow shapes, or "Chevrons", laid on the road surface at regular intervals (Lafont, 1985). Drivers should leave two Chevrons between the front of their vehicle and the rear of the vehicle they are following, in order to maintain a reasonably safe following-distance. Chevron markings have been trialled in the United Kingdom on the M1 motorway in Leicestershire and later in Northamptonshire, where traffic flows are higher.

Measurements were made of the gaps between vehicles (from the rear of one to the front of the next) and of their speeds. Some drivers took part in a questionnaire survey at a nearby motorway service area. Accident data were also collected. The day-to-day management of the trial was performed by Messrs Halcrow Fox & Associates on behalf of the then Transport and Road Research Laboratory.

2. THE TRIAL SITES

The general layout of the two sites was similar and that for the Leicestershire site is depicted in Fig 1. This site was between M1 junctions 20 and 21 and was chosen because it was reasonably straight, with gentle gradients and a long distance between junctions, so that merging and weaving traffic would have a minimal effect on the data. The flow was modest for a motorway at 25,000 vehicles (AADT one-way). The markings were laid on 19 May 1990.

The second site was situated south of the Watford Gap service area, between junctions 17 and 16 in Northamptonshire. The traffic flow here was 55,000 (AADT one-way) reducing to 47,400 when the M40 motorway was opened early in 1991. The markings were installed here on 18 December 1990.
3. THE MARKINGS

The markings were laid every 40 metres in lanes 1 and 2 of the motorway. Their detailed dimensions are given in Fig. 2. At typical motorway speeds (about 70 mph - 110 km/h) the separation of two Chevrons should produce following gaps of between 1.6 and 2.0 seconds, allowing for the road length cut off by a car bonnet and the driver's need to see some road surface before and after the two Chevrons in view. Two seconds is the following time recommended in the British "Highway Code".

The markings were laid in two lanes only (Lanes 1 & 2) to allow their effect on an adjacent lane to be assessed. Lane 3 was the lane left unmarked because there was insufficient space on the central reserve for repeater signs, which it was considered would be necessary, whilst the markings were unfamiliar.

A "Moving Lane Closure" was used for the process of laying the markings. This consisted of a slow-moving convoy of lorries, equipped with warning signs and lights, in the middle of which worked the team carrying out the Chevron laying.

At the first trial site in Leicestershire, the markings were laid using temporary materials. This reflected concern that it should be possible to remove the markings quickly and without damage to the carriageway should the trial markings have adverse effects on traffic behaviour, or safety. These temporary markings were considerably less durable than had been anticipated. They were refurbishied before measurements were made three months after installation, but a significant proportion were in poor condition towards the end of the six months trial period, at which time it was not considered worthwhile to refurbish them again. The markings in Northamptonshire were installed in "permanent", thermoplastic material.

4. THE SIGNS

It was necessary to provide roadside signs to advise drivers how to use the markings. Fig. 3 shows the signs used. "Check your distance" appeared before a driver encountered the Chevrons; four "Keep Apart, 2 Chevrons" signs were situated at about 700 metre intervals (to take advantage of existing crash barriers); and a final "Keep your distance" was just after the end of the markings.

5. DATA COLLECTION

Three different sources of data were used in assessing these markings:

   Traffic data (following-gaps and speeds)
   Questionnaire survey data
   Accident data

A comprehensive description of the traffic and questionnaire data may be found in TRL Report CR304 (Webster, Skinner & Helliar-Symons, 1992).

5.1 Traffic Data

Recording equipment was installed in roadside cabinets at three points relative to the markings:

   Station A - before the markings (Control data)
   Station B - on the markings (to investigate any immediate effect)
   Station C - downstream from the markings (to investigate any sustained effect)

Station C was about 3.5km downstream of the Leicestershire site and 1.5km in Northamptonshire.
There were five data-collection periods to allow investigation of any behavioural changes with time:

- Before laying
- One Week After
- One Month After
- Three Months After
- Six Months After

In each of the three motorway traffic lanes large and small (< 6.5 metres) vehicles were recorded separately. Every hour an histogram of following gaps and vehicle speeds were saved for subsequent analysis. At each data-collection period, data for a minimum of 20,000 vehicles were collected during daylight hours, with dry road conditions, on at least two different days.

5.2 Questionnaire Survey Data

Attitude surveys were undertaken at a motorway service area close to the Leicestershire site approximately one week and six months after the laying of the carriageway markings, to examine drivers' initial views and see whether these had changed after a substantial period of operation. At the Northamptonshire site, the surveys were carried out at one week After only. A Six Months After survey was not carried out here because the results for the first three interview surveys showed a very considerable measure of agreement.

The questionnaire investigated the level of driver perception and understanding of the markings; whether drivers attempted to use the markings and experienced any difficulties; and the extent of any modification to their behaviour (self-assessed).

Interviews were undertaken in the car and goods vehicle parking areas of the first motorway service area encountered after the markings. These were 10 km and 9 km after the Chevrons in Leicestershire and Northamptonshire respectively. Interviewers were required to select a specified cross-section of drivers (by age, sex and vehicle type).

5.3 Accident data

Accident data were received, as a print-out from the TRL STATS19 database, for all accidents (both carriageways) from the motorway junction before the Chevrons to the next junction "downstream", at 6 km in Leicestershire and at 3.5 km in Northamptonshire. ‘Before’ data were received for the 3 years prior to each installation. Six months and twelve months after data were available from Leicestershire and Northamptonshire respectively.

6. DATA ANALYSIS

6.1 Traffic data

Two categories of close-following were examined: with gaps of less than one second (most dangerous) and less than two seconds (Highway Code advice). Clearly, the largest change would be expected to occur in the former category, as many drivers who improve their following behaviour may not do so by a sufficient margin to remove them from the under two seconds category completely.

The data recording equipment was not totally reliable and there were a number of gaps in the data which are indicated in the tables.

Station A, located before the Chevron markings were reached, was used to provide Control data. Changes in following behaviour were calculated and their significance measured with the chi-squared statistic. The changes on the Chevrons and downstream were calculated relative to those at the Control site. Changes in speeds were similarly analysed using a 't' test.
Tables 1 and 2 present, for all vehicles in lanes 1 and 2, the changes in following gaps of less than 1.0 second. In Leicestershire, there was a decrease in the close-following on the Chevrons which declined with time. By six months after, the temporary markings had deteriorated noticeably, and the initial large change in close-following had reduced to a small non-significant level. Downstream from the Chevrons there was not a reduction in close-following but a significant and unexpected increase.

In Northamptonshire, with higher flows and permanent thermoplastic markings, the results proved to be more stable. Close-following behaviour improved both on the markings and downstream and did not deteriorate appreciably with time.

Two points of interest emerged from the detailed analysis of the data by lane and vehicle size (Webster et al, 1992). One was that a bigger proportion of large vehicle drivers in Lane 1 reacted to the Chevrons than did car drivers in Lane 1 or large vehicle drivers in lane 2. (Large vehicles, except coaches, are not allowed in Lane 3 of UK motorways, therefore Lane 2 is used for overtaking). The other was that drivers in Lane 3 were being influenced by the Chevrons in the adjacent lane, but to a lesser extent than drivers in Lanes 1 and 2.

Tables 3 and 4 indicate the effect of the Chevrons on vehicle speeds. Changes in vehicle speeds were generally small and of little practical significance (although the changes showed as statistically significant because of the quantity of data collected). The exception was the downstream monitor in Leicestershire, where there appeared to be a 10% increase in speeds. This was not repeated in Northamptonshire.

6.2 Questionnaire Data

Nearly 500 respondents were interviewed in the questionnaire survey in Leicestershire in the week after the markings were laid. A further 300 were questioned in the Six Months After Survey, with a similar number again in Northamptonshire immediately after the markings were laid.

The responses to the more important questions are given in Table 5. Clearly, the overwhelming majority of drivers noticed the trial, understood its purpose and tried to use the markings. About a quarter encountered some difficulty when they used them which they attributed to: cars entering "their" gap (42%), the Chevrons being a distraction (18%), other difficulties (40%). The majority thought the Chevron spacing "about right" with roughly equal numbers thinking them "too close" or "too far apart". Almost all respondents found the markings either "helpful" or "very helpful".

The data was also examined by age, sex, occupational class, and driving experience of the respondent, by journey purpose and vehicle type driven. Some interviews were conducted after dark. Very few statistically significant differences were found in the analysis of these sub-groups. The only two differences of practical significance were that motorcyclists and young drivers (<25 years) were less likely to use the markings. Motorcyclists should be less vulnerable than four-wheeled vehicles, if they close-follow, because their machines are more manoeuvrable and they have a wider choice of "escape" routes than do drivers. The result for young drivers may reflect the over-confidence of youth, and would be very difficult to counteract.

6.3 Accident data

Accidents which occurred at or after the start of the Chevron markings up to the next junction were used as the Test group; accidents before the Chevrons and on the opposite carriageway were used as the Comparison group. Both groups were split into accidents occuring before and after installation of the markings. Multi-vehicle cross-over accidents were excluded and the effect on single-vehicle accidents was examined separately from, and also together with multi-vehicle accidents.

Accident reductions occurred at each of the two sites after the introduction of the Chevron markings. These are detailed in Table 6, with the actual data for "All Accidents" in Table 7. The third column of Table 6 indicates the results using, as an alternative control, all accidents which occurred on the M1 Northbound between M25 (London) and M6 (Birmingham), during the same time periods. If the Leicester and Northamptonshire data are combined, then the changes are significant at the 5% level for all categories.
The large effect on single-vehicle accidents was not expected from a measure designed to increase the separation between vehicles and hence reduce rear-end collisions. It therefore seems likely that the markings act as an alerting device, in an environment which is not rich in visual information, and thus help avoid single-vehicle accidents as well.

Changes in accidents were also examined for 34 km downstream from the Northamptonshire site (to junction 14). No evidence was found of any accident migration from the lengths marked with Chevrons. However, the effect of the Chevrons was no longer detectable just after junction 16, about 5 km from the end of the marked section.

The accident data on which these results are based is only for six months after installation of the Chevrons in Leicestershire and for twelve months after in Northamptonshire. It is very likely that the changes quoted are larger than the underlying effect, because of the novelty of the markings. It is, therefore, probable that if Chevrons were used in a more widespread way, the size of the change would be smaller. However, if there were many more Chevron patterns, they might be expected to have an educative effect, helping drivers to choose and maintain safer spacings when not actually travelling over the markings. If this were so, then, as the number of sites increased, the loss of any novelty effect would be likely to be offset partly by a general improvement in close-following behaviour at and away from the markings.

Making a very conservative estimate based on the indicated reduction in accidents, it seems likely that the cost of providing these markings would be repaid in saved accident costs within twelve months of installation.

7. DISCUSSION

In any trial of this nature the goal is to reduce accidents. However, accidents generally accrue slowly and a behavioural measure is used as a proxy. In this case the behavioural measure was the gap between vehicles.

At the first site in Leicestershire temporary markings were used, which deteriorated quickly. The behavioural data showed an initial decrease in close-following, which reduced with time, but did not quite return to the before level. This would be compatible with the deterioration of the markings, particularly when coupled with the more sustained effect in Northamptonshire.

After drivers have crossed the markings, one might reasonably expect the effect on their close-following behaviour to be sustained for some further distance. Close-following was therefore monitored downstream from the markings to investigate this effect. Surprisingly, in Leicestershire close-following increased downstream from the markings. In Northamptonshire, it decreased but, as had been expected, with a smaller reduction than was observed on the markings.

The downstream result in Leicestershire is anomalous and, when coupled with the Northamptonshire results, no sensible explanation for this change can be offered.

The questionnaire surveys produced very similar results to those in France. The public noticed, understood and tried to use the signs and markings. Naturally, there were some reservations, but a very substantial proportion of those interviewed (about 90%) thought them helpful or very helpful.

The reduction in accidents was better than expected despite the relatively short After period at each site. Whilst there may be a substantial novelty effect in these results, it is nevertheless likely that the underlying effect is worthwhile and that the measure will be very cost-beneficial.
8. CONCLUSIONS

1. The M1 Chevron trial has produced an initial large reduction in accidents of both multi-vehicle and single-vehicle types.

2. With one anomalous result, the markings have improved close-following behaviour.

3. The concept has been well received by those members of the public questioned in an interview survey.

9. ACKNOWLEDGEMENTS

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10. REFERENCES


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Visual Guidance in Road Work Zones

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VISUAL GUIDANCE IN ROAD-WORK ZONES (SHORT FORM)

Work zones represent a discontinuity for drivers in terms of driving speed and roadway characteristics and therefore a region of potential danger. To lead a driver through these areas, there is a need of good visual guidance. That's why there was made a study on work zones and their visual guidance.

An analysis of the existing delineation systems and arrangements used in work zones showed the following result:

Beacons with red and white stripes are commonly used in all areas of a working zone. Their task is to reduce speed and to improve the attention of the driver and furthermore to lead the driver through the work zone. In combination these factors lead to a poor visual guidance.

The primary aim of this investigation was to optimize visual guidance so that the driver knows at every time in the work zone how to conduct his vehicle.

The way to realize this is the following:

- marking the work zone as a unit
- marking the beginning and the end of a work zone
- marking special areas with different shapes, heights, colors and arrangements

The work zone is to be divided into several areas (starting area, delineation area, working area and end area). These different areas will be coded by different heights, colors and shapes of their traffic devices. For every task you get a special clear marking.

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1 Introduction
Work zones represent a discontinuity for drivers in terms of driving speed and roadway characteristics and therefore a region of potential danger. To lead a driver through these areas, there is a need of good visual guidance. That’s why there was made a study on work zones and their visual guidance.

2 Basic problems
An analysis of the existing delineation systems and arrangements used in work zones showed the following result:
All the situations in a work zone look alike, but they are very different. The reason why they all look alike is the following. All panels have the same height, they are all red and white. This leads to the same appearance and to visual clutter. The driver does not know how to guide his car through the work zone, he slams the brake and behaves in an unpredictable way. The other following drivers can’t stop in time and already you have a lot of accidents.

3 Solution for these problems
The first step to a solution is to divide the work zone into areas according their task. You have to distinguish between:

- information area
- lane changing area
- working area (incl. exit)
- lane changing area
- end area

A work zone starts with the information area, which gives an overview of the layout. Speed limits and other informations are presented to the driver. From this area the driver directly comes to the lane changing area where he has to follow the curve of his lane. In the working area you normally find a straight road and a division to the construction zone. Sometimes you have an exit within this area. After the working or construction area the lane changing area follows again. So each area has its own task and demands therefore a special layout.
4 Computer simulations

The first tests to find out the influence of different parameters were done by computer simulation.

Fig. 1: threedimensional model by computer simulation

Figure 1 shows a threedimensional modell from above (left side) and from the drivers view (right side). Standard situations (turn to left, turn to right, stop, V-form) have been examined depending on

the height of the elements and
the position of the elements

Fig 2: different positions

Figure 2 shows two typical situations. The left situation is comparable with markers on the surface of the road, the right is comparable with the lamps on top of panels. The investigation leads to the result:

**the higher the position of the elements the lower the guidance.**
Figure 3 shows the same situation with different element heights. It can clearly be seen that visual guidance increases with the height of the elements. For good visual guidance a minimum height is required.

5 Model street 1:10

The next step of the investigation was the test of complex situations depending on day- and nighttime conditions on the model street 1:10 (Fig. 4). The testing methods were reaction time and ratings by test persons. The best results are to be seen in figure 5 (right side, new design).
In lane changing areas and exits an optimum is to have low elements at the inner side and high elements on the outer side. The driver can overview the low elements. The high elements are recognizable even if there is a car in front. For straight roads low elements can be used.

6 Basic concept
The primary aim of this investigation was to optimize visual guidance. The way to accomplish this is the following:

Division of the work zone into the above mentioned areas and

- define the work zone as a unit by
- marking the start- and endposition
- marking special areas with
different height, color and design
7  Preview

The next two pictures show the old and the new design in a complex situation. There exists a defined starting point of the work zone and an optimized optical guidance in the lane changing area. This new design is under real traffic on a german highway at this time.

Old design

New design
Restructuring of Town Entrances on Roads Classified as Major

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Restructuring of town entrances on roads classified as major

ABRIDGED VERSION

The road engineering administration of the district of Neuss has been restructuring town entrances on district roads for more than 5 years. These transformations are designed to achieve the following aims:

- improvement of road safety
- speed reduction of vehicles
- improvement of the cyclists situation
- revaluation of residential areas

By making the necessary structural changes we should achieve already at the entrance to the town our objective of enforcing compliances with innercity speed limits while the connecting function of the road should not be affected considerably.

The following types of measures have been applied:

- narrowing of the pavement
- refuge islands
- strips of pavement stones
- speed bumps (of plaster or asphalt)
- planting of trees
- combination of the above mentioned types of measures.

The efficiency of these restructuring measures has been checked by "before and after" studies (accident occurrence, speed behaviour of motorists, residents opinion).

Concerning accident occurrence the measures have achieved throughout positive effects. The major part of the town entrances were either free of accident in the first years after the restructuring or they indicated a reduced accident occurrence.

Depending on the extent of the measures taken, the success of the speed reduction varied considerably. Whereas measures without speed bumps reached average reductions of about 5 km/h, the effectiveness with speed bumps at town entrances was clearly greater (up to 20 km/h). All measures successfully reduced the maximum speeds. The speed limit of 50 at town entrances, however, could not be maintained in any case.

Basically the residents welcome the measures. The measured speed reductions, however, are either not being noticed at all or classified as insufficient. The expectations of the residents go partly beyond the envisaged aims connected with the restructuring.

In general the measures could reach positive effects. The speed bumps of asphalt as a new element have proved to be efficient so far. They avoid noise nuisances caused by using pavement stones, and remarkably reduce the speed of the vehicles.
1. Introduction

The town entrance marks the transition from the rural roads to innercity roads. Whereas speeds of up to 100 km/h are permitted on rural roads in Germany, the legal speed within city limits is 50 km/h. For reasons of road safety it is desirable that the motorists adjust to this speed limit already before reaching the town entrance and that they actually do not drive faster than 50 km/h inside town. Reality, however, shows that the process of speed reduction is not initiated until quite late. Consequences are obvious speed violations at the city limit sign. The motorists coast into town and thus maintain the excessive speeds till far into town.

Fig. 1: Speed limits in town entrance

These high speeds are especially problematic if there are institutions calling for caution at the edge of town, as for instance schools. Cycle traffic is a further problem, particularly if the rural cycle tracks end at the town entrance and the cyclists are led into the carriageway.

In spite of the massive speed violations town entrances in general do not represent black spots. Utilisation is mostly low, pedestrians crossings are rather rare so that high speeds in the very near of town entrances often do not have consequences. As these high speeds, however, are transferred into more sensitive areas, the town entrance possesses a kind of key position for road safety. If it were possible to enforce compliance with the legal speed limit at the town entrance, an improvement of the situation of residents, pedestrians and cyclists could also be achieved for the adhering innercity areas.
Within the last few years numerous town entrance areas have been restructured for the above mentioned reasons. Stress was rather laid on town entrances of smaller towns and communities as the transition from rural roads to innercity roads is more marked. Because of a continuous expansion of settlement or the establishment of trade centres the transitions at the edge of big towns are more fluid. The proportion of through traffic in rural areas is also higher so that the motorists consider the towns as obstacles in their way. The willingness of these motorists to adjust to speed limits on their way through the towns is usually very low.

2. Measures

While restructuring town entrances different types of measures have been applied. The two basic types of construction are the narrowing of the pavement and the refuge island. Mostly in addition to these types alterations of the surface (pavement) or raising of the pavement level are used. In general all restructurings are landscaped. Combinations of the various elements are also applied.

2.1 Narrowing of the pavement

Narrowings of the pavement are elements of design which reduce the width of the road on a limited stretch. The narrowing can be effected from both sides or only from one side. Rural roads are mostly wider than 7 m. With a narrowing to 6.50 m even lorries and buses can cross at speeds of more than 50 km/h; for the crossing of cars this is the same at a narrowing to 4.75 m. As furthermore crossings in the narrowing are extremely rare at a traffic density of lower than 5000 vehicles per day these narrowings themselves do not represent a restrictive measure which could force motorists to maintain 50 km/h. At ending cycle tracks narrowings offer the advantage to direct cyclists onto the lane in the shelter of the narrowing. Furthermore, no acquisition of land is normally necessary for the construction of a narrowing.

Fig. 2: Narrowing
2.2 Refuge islands

With the help of refuge islands the approaching motorist clearly sees a constructional element in the middle of the road from far away; especially visible are refuge islands with tree plantings. The lanes next to the island are effected in widths between 3.00 and 3.50 m. These widths of the lanes do not represent a considerable restriction for the motorist, on the other hand, the extent to which the lanes swerve is of great significance. If the lane is swerved sharply, definite steering movements are necessary to drive through the structure. Thus, an adjustment to speed is forcibly achieved at these refuge islands. Structures of this kind, however, often require an acquisition of land, furthermore, a safe integration of the cycle traffic - in case of an ending cycle track - is more difficult.

Fig. 3: Island

Fig. 4: Pavement stones
2.3 Alterations of the road surface

In general roads are surfaced with asphalt. By adding stones of pavement on a certain stretch the material of the road surface is changed. This element of design is used for two reasons: either the strips of pavement stones at the edge are intended to achieve a further optical narrowing of the road or the motorist shall be warned, that is to say reminded by the noise development (the whole lane is made of pavement).

While driving on pavement, however, there are often shifts in noise frequencies which result in the noise of the vehicles being perceived as very unpleasant by the residents. For this reason pavement is used rather rarely, numerous measures have been rescinded due to residents' complaints.

2.4 Raisings of the road surface

Speed bumps are known from the improvement of traffic conditions for residential areas. There, they are effected in pavement at a varying inclination of the ramp. On the one hand, the ramp is an effective means to reduce speed, but on the other hand, if too steep, it can cause problems when driven over. For reasons of noise nuisance speed bumps are rarely applied at town entrances. The Bureau of Structural Engineering of the district of Neuss, however, has developed a procedure in the last years to effect raisings of the road in asphalt. With the help of these raisings a speed reducing effect similar to speed bumps can be achieved - while avoiding the negative noise effects.

Fig. 5: Raising of the road surface made of asphalt

3. State of research

The most recent recommendations for the restructuring of town entrance areas are the results of a research project of the department of town development and traffic of North-Rhine Westphalia from 1991 /2/. In a project, 27 short town
crossings (shorter than 1 km) were restructured with the help of various measures. The roads showed traffic densities between 2,000 and 8,000 vehicles per day, the towns had fewer than 10,000 inhabitants. Before and after, speed measurements, analyses of accidents and surveys of road users were undertaken.

The authors sum up that at the restructured town crossings the number of accidents with personal injury and/or extensive material damage was reduced more noticeably than in the control group of non-restructured town crossings. In general the project was evaluated positively in respect to the improvement of road safety. The speed reductions varied considerably, they were higher if the motorists drove very fast before the restructuring (70-80 km/h). Motorists can only be led to an adjusted driving behaviour by strict measures like a clear swerving of the lane or speed bumps.

In the detailed analysis, positive effects on accident occurrence were observed at narrowings and alterations of the road surface at town entrances, whereas at refuge islands an increase from 16 accidents in 2 years before the restructuring to 21 accidents in 2 years after the restructuring was noticed. For this reason, the constructional narrowing combined with leading the cycle traffic into the road behind the narrowing is recommended for the design of town entrance areas; whereas refuge islands with swerved lanes are not advisable.

However, in the preliminary recommendations for the construction of major roads (EAHV) /4/ you can read: "speed reductions by refuge islands are to be expected in particular if the width of the lane which remains next to the island is low and/or the refuge island contains a swerve. This combination of measures is especially applicable for town entrance areas of villages and smaller towns." This statement contradicts to a certain extent the recommendations from North-Rhine Westphalia.

The EAHV also comments on the alterations of the road surface. They are considered to be a good possibility to point out a changed characteristic of the road as for instance the entrance roads into villages and smaller towns.

After examining the recent research results it does not seem advisable to exclusively recommend one of the two basic solutions narrowing and refuge island.

4. Results of my own research

The Bureau of Road Engineering of the district of Neuss has been restructuring town entrances on district roads for more than 5 years. These transformations are designed to achieve the following aims:

- improvement of traffic safety
- speed reduction of vehicles
- improvement of the cyclists' situation
- revaluation of residential areas.
Our bureau checks the efficiency of these restructuring measures by "before and after" studies. Analyses of accidents, speed measurements and surveys of residents are undertaken. Based on these results the concepts for future restructurings are continuously checked and if necessary modified. There is continuous feedback between planning and efficiency control /1/, /3/.

Today I can report about the results at 13 restructured town entrances, at 5 additional town entrances the "after" studies are presently being undertaken; furthermore I would like to present some new plans of town entrances which are going to be restructured within the next months.

4.1 The observed town entrances

<table>
<thead>
<tr>
<th>Nr. town entrance</th>
<th>traffic density vehicles/day</th>
<th>type of measure</th>
<th>characteristics</th>
<th>width of the road [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Schlicherum</td>
<td>1800</td>
<td>Narrowing</td>
<td>Pave. stones</td>
<td>5,0</td>
</tr>
<tr>
<td>2 Vorst</td>
<td>3500</td>
<td>Narrowing</td>
<td>Pave. stones</td>
<td>5,5</td>
</tr>
<tr>
<td>3 Driesch</td>
<td>3500</td>
<td>Narrowing</td>
<td>Pave. stones</td>
<td>5,5</td>
</tr>
<tr>
<td>4 Hochneukirch</td>
<td>750</td>
<td>Narrowing</td>
<td>Pave. stones</td>
<td>5,5</td>
</tr>
<tr>
<td>5 Bedburdyck</td>
<td>1600</td>
<td>Narrowing</td>
<td>Pave. stones</td>
<td>5,5</td>
</tr>
<tr>
<td>6 Lüttenglehn-West</td>
<td>4000</td>
<td>Narrowing</td>
<td>Pave. stones</td>
<td>5,5</td>
</tr>
<tr>
<td>7 Lüttenglehn-Ost</td>
<td>4000</td>
<td>Narrowing</td>
<td>-</td>
<td>5,5</td>
</tr>
<tr>
<td>8 Greifrath-Ost</td>
<td>10000</td>
<td>Narrowing</td>
<td>-</td>
<td>6,0</td>
</tr>
<tr>
<td>9 Neukirchen-West</td>
<td>-</td>
<td>Narrowing</td>
<td>Pave. stones</td>
<td>6,0</td>
</tr>
<tr>
<td>10 Neukirchen-Ost</td>
<td>3500</td>
<td>Narrowing</td>
<td>Pave. stones</td>
<td>6,0</td>
</tr>
<tr>
<td>11 Greifrath-West</td>
<td>4500</td>
<td>Island</td>
<td>-</td>
<td>2,75/2,75</td>
</tr>
<tr>
<td>12 Neuenbaum</td>
<td>4600</td>
<td>Narr. + Island</td>
<td>-</td>
<td>5,5</td>
</tr>
<tr>
<td>13 Evinghoven</td>
<td>2300</td>
<td>Island</td>
<td>Raising</td>
<td>2,5/2,5</td>
</tr>
</tbody>
</table>

Table 1: Survey of the observed measures

In the first phase (1985-1987) the Bureau of Road Engineering pursued the concept of narrowings. The widths of the lanes were about 5,50m while the road was optically further narrowed by strips of pavement stones. In the second phase, also refuge islands were applied as well as combinations of refuge islands and narrowings.
The significant innovation in this phase, however, was the road raising made of asphalt. These raisings had ramps of 8 cm on a length of 3 m. They have no horizontal plane, but only obtain a rounding of the dome. The inclination of the ramps corresponds to a proportion of about 1:35. The raisings can be negotiated at 50 km/h without difficulty. The vehicle experiences a dip. The restructuring is marked by a traffic sign and an applied white triangle.

In the accident analyses accidents with personal injuries and/or extensive material damage were evaluated. Outside city limits an area of 1000 m before the town entrance was observed and within city limits an area of 300-500 m behind the town entrance. Accident occurrence is usually very low - about one accident per year. The "before-after" comparison resulted in a reduction of the numbers of accidents; whereas on the average 1.1 accidents per year occurred at the 13 town entrances prior to the restructuring, this number decreased to 0.6 accidents afterwards. At most town entrances the number of the accidents was reduced, 4 town entrances have been accident free since the restructuring. In 4
additional towns the number slightly increased although these are no accidents which are directly connected with the structure. Furthermore it is to be taken into consideration that traffic density at the town entrances increased up to 10 % per year. On the whole, the restructuring measures reached positive effects on the road safety.

Fig. 8: Average accident occurrence before/after

4.3 Vehicle Speeds

Measurements of speed were taken at all the town entrances at three cross sections on the open road, in the vicinity of the structure at the city limit sign and at the center of town. The analyses demonstrate that no significant changes in speed resulted from the restructuring measures on the open stretch of road and at the center of town. The effects were limited to the immediate area of the structure. 85 %-speed and the frequency with which the 70 km per hour mark (top speed) was exceeded were used in describing the speeding behaviour.

Prior to restructuring, the speeds driven at the city limits sign lay primarily between 75 and 85 km per hour. In every town reductions in speed occurred, so that the levels then varied between 60 and 75 km per hour. The decreases varied among the 13 towns between 2 and 14 km per hour; at one place an especially large change of 22 km per hour occurred. On average, the speeds decreased by 9 km per hour. Since the largest portion of the measures are narrowings of the pavement, no system comparison to refuge islands is possible. The greatest effect was achieved with raising of the road surface at the refuge islands.
### Table 2: Speeding behaviour at city limits sign

The maximum speeds decreased in the case of every town. While between 25 and 50 % of the drivers had driven over 70 km per hour at the city limits sign before the restructuring, these percentages lay between 0 and 25 % afterwards. These positive reductions do not mean, however, that a speed limit of 50 was maintained at the town entrances. In the best cases "only" 2/3 of the drivers drive over 50 km per hour, in general, after the restructuring this percentage was still at 80-90 %.

<table>
<thead>
<tr>
<th>Nr.</th>
<th>Town Entrance</th>
<th>85%-Speed (km/h)</th>
<th>Percentage of High Speeds (70 km/h or more)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Before</td>
<td>After</td>
</tr>
<tr>
<td>1</td>
<td>Schlicherum</td>
<td>68</td>
<td>60</td>
</tr>
<tr>
<td>2</td>
<td>Vorst</td>
<td>71</td>
<td>64</td>
</tr>
<tr>
<td>3</td>
<td>Driesch</td>
<td>74</td>
<td>72</td>
</tr>
<tr>
<td>4</td>
<td>Hochneukirch</td>
<td>81</td>
<td>67</td>
</tr>
<tr>
<td>5</td>
<td>Bedburdyck</td>
<td>79</td>
<td>71</td>
</tr>
<tr>
<td>6</td>
<td>Lüttenlehnh-West</td>
<td>82</td>
<td>75</td>
</tr>
<tr>
<td>7</td>
<td>Lüttenlehnh-Ost</td>
<td>78</td>
<td>71</td>
</tr>
<tr>
<td>8</td>
<td>Grefrath-Ost</td>
<td>77</td>
<td>73</td>
</tr>
<tr>
<td>9</td>
<td>Neukirchen-West</td>
<td>83</td>
<td>71</td>
</tr>
<tr>
<td>10</td>
<td>Neukirchen-Ost</td>
<td>78</td>
<td>69</td>
</tr>
<tr>
<td>11</td>
<td>Grefrath-West</td>
<td>74</td>
<td>69</td>
</tr>
<tr>
<td>12</td>
<td>Neuenbaum</td>
<td>76</td>
<td>62</td>
</tr>
<tr>
<td>13</td>
<td>Evinghoven</td>
<td>76</td>
<td>54</td>
</tr>
</tbody>
</table>
The table indicates that in the case of every town entrance the speeds were lower than before. It shows, in addition, that clear decreases occurred at town entrances previously showing high speeds.

The analyses indicate that all restructuring achieved speed reductions. The changes vary widely, however. The raising made of asphalt showed a definite effect. The speed level was reduced by 20 km per hour. After restructuring no driver drove faster than 70 km per hour.

4.4 Survey results

The residents of the town entrances were given a written survey regarding the restructuring. Approximately 50 % of those surveyed responded. On the whole, these persons responded positively to the efforts of the Road Engineering Bureau to improve the road conditions at the town entrances; however they did have further ideas as to the restructuring and had higher expectations for speed reduction. Many residents call for closing off the street, for a bypass, or for measures such as a speed limit of 30 km per hour, which had never been considered by the officials in order to maintain the function of the street. Due to the large difference in conceptualization, the Bureau decided to involve the residents more intensively in the future and to undertake a referendum about planning early on.

Of those surveyed, only 17 % believe that the situation was safer after the restructuring; nearly half see no change, 40 % say even that the situation was more dangerous than before. In regards to the vehicle speeds, the general impression predominates that no decisive changes were effected by the restructuring (78 %). 15 % are of the opinion that people now drive slower, 7 % say they have noticed an increase in speeds. When the perceived speed is
compared with the measured speed, one sees that the results vary widely for 3 town entrances: whereas the residents say the speeds had increased, the measurements indicate reductions between 7 and 12 km per hour.

The survey therefore demonstrates that the residents clearly have more ideas regarding reduction of speed and regarding general traffic calming at the town entrances (also regarding the reduction of traffic density) than does the Road Engineering Bureau. The level of traffic cannot be reduced by restructuring. In the future, a greater decrease of speeds driven is to be targeted, however, and the populace further involved in the planning.

<table>
<thead>
<tr>
<th>Nr. town entrance</th>
<th>increased</th>
<th>decreased</th>
<th>worse</th>
<th>improved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schlicherum</td>
<td>1</td>
<td>15</td>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td>Vorst</td>
<td>1</td>
<td>7</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Driesch</td>
<td>0</td>
<td>8</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Hochneukirch</td>
<td>0</td>
<td>9</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Bedburdyck</td>
<td>1</td>
<td>6</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Lüttinglehn-West</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Lüttinglehn-Ost</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Grefrath-Ost</td>
<td>0</td>
<td>11</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Neukirchen-West</td>
<td>4</td>
<td>7</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>Neukirchen-Ost</td>
<td>1</td>
<td>9</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>Grefrath-West</td>
<td>0</td>
<td>7</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Neuenbaum</td>
<td>0</td>
<td>13</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Evinghoven</td>
<td>1</td>
<td>7</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>

| all entrances     | 7 %       | 78 %      | 15 %  | 40 %     | 43 %     | 17 %     |

- : there are no results of the survey

Table 3: Selected survey results
5. Conclusions and current planning

On the basis of the results and observations of the past years, the Road Engineering Bureau of the District of Neuss continues its efforts to improve the traffic conditions at town entrances. The plans for 9 more town entrances are completed, the construction will follow in the upcoming months. Narrowing as well as refuge islands will be used.

Fig. 10: Refuge islands (planning)

Fig. 11: Narrowing (planning)
At the refuge islands, the lanes are to swerve sharply in order to decrease the speed even more. The measures are relatively extensive and expensive.

The narrowings are considerably easier and are constructed with an eye to their form. The following planning principles were the foundation for them:

a) A raising of the road surface made of asphalt at the narrowing is intended to insure reduction of speed
b) Bilateral symmetrically laid kerbs reduce the width of the lane to 4.50 m vertical elements (trees, marker posts) and a white triangle at the ramp are to guarantee the visibility; the narrowings are illuminated
c) Beyond the narrowing the bicycle traffic is safely directed into the lane of traffic
d) The structure is marked in advance (50-60 m) by signs and reflecting strips.

The costs for these narrowings are under DM 30,000 per structure. The observations in upcoming years will show whether the intended improvements can be better achieved via this new generation of restructuring measures.

Works cited:


4) Forschungsgesellschaft für Straßen- und Verkehrswesen (Herausgeber): Empfehlungen für die Anlage von Hauptverkehrsstraßen EAHV, Köln 1992 (Entwurf)
Right Turns on Red by a Constant "Green Arrow Sign"

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Berlin Branch

RIGHT Turner ON RED BY A CONSTANT "GREEN-ARROW-SIGN"
--Advantages and disadvantages of a special form of
regulation taking account of the risk of accidents by right turns
on red and right turns on green--

Dipl.-Ing. Klaus Krause

Abstract

Before the unification of Germany, the Highway Code of the GDR
included the provision of sign 23 (green arrow) relating to right
turns on red at signal-controlled junctions.

At the present time, a transitional arrangement for the new states
of the Federal Republic of Germany has been made under the German
Highway Code (StVO) providing for the continued "Possibility of
Right Turns on Red" as long as a stationary sign displaying a
green arrow is attached to the signal installation. This special
right-turns-on-red regulation is currently being studied by the
Federal Highway Research Institute (BASt).

VTI RAPPORT 380A
An initial brief study of the green arrow regulation was undertaken in 1991. Within the framework of the now completed research effort, the following investigations had been carried out in the new federal states:

- accident investigations;
- observations of traffic conflicts;
- speed measurements;
- studies of reconstructed events;
- interview surveys of local authorities and drivers.

The results of these studies reveal the advantages and drawbacks of the use of the green arrow sign as regards road safety and the capacity of signal-controlled junctions equipped in this manner.

The following research findings should be pointed out:

1) No important detrimental effects of the green arrow sign regulation permitting right turns on red on the safety of pedestrians and cars could be established.

Compared with the right-turns-on-green regulation, previous research findings neither revealed special increases in accidents nor a higher rate of conflicts under the right-turns-on-red arrangement.
2) Improvement not only of the right turns capacity but also the overall capacity of the observed green-arrow-sign-equipped, signal-controlled junctions.

3) Reduction of junction construction costs.

4) The green arrow arrangement cannot be applied unreservedly. In addition to the application conditions and recommendations included into the GDR Technical Standard (TGL 12096/04), further application criteria need to be defined.

The following supplementary measures are desirable:

- Educating road users to display the correct regulation behaviour
- Improving the optical and psychological effects of the green arrow.

BAST is currently preparing for a model test on this problem which will be undertaken in the old federal states.
RIGHT TURNS ON RED BY A CONSTANT "GREEN ARROW SIGN" --Advantages and disadvantages of a special form of regulation taking account of the risk of right-turn-on-red and right-turn-on-green accidents
Dipl.-Ing. Klaus Krause
Berlin Branch
Bundesanstalt für Strassenwesen
Federal Highway Research Institute (BASt)

Foreword

Before the unification of Germany, the Highway Code of the GDR included the provision of sign 23 (a constant green arrow) permitting right turns on red at signalized junctions (cf. Fig. 1).

At the present time, a transitional arrangement for the new states of the Federal Republic of Germany has been made under the German Highway Code (StVO) providing for the continued "Possibility of Right Turns on Red" as long as a stationary sign displaying a green arrow is attached to the signal installation. This special right-turn-on-red regulation is currently being studied by the Federal Highway Research Institute (BASt).

A regulation permitting right turns on red instead of the obligation to stop did not only exist in the former GDR. Similar regulations are in application in some European states and in most states of the U.S.

Technical principles

An essential aspect of signalization planning is the striking of the best compromise possible between the safety and capacity of junctions.

A signalization plan with many phases to accommodate a great number of separate traffic movements generally involves detrimental effects on capacity on account of the required change intervals and lost times involved.

A signalization plan with few phases is generally allocated to a combination of traffic movements which receive the right-of-way simultaneously during one or more intervals.

Here the green arrow sign regulation offers the possibility of doing without a separate phase in the case of heavy right-turn movements and may even allow an overall reduction of green times. In essence, the demand for the continued permission of the right-turn-
on-red regulation primarily aims at improving the capacity of junctions.

Task

By letter of 15-04-1991, the Federal Highway Research Institute (BASt) was commissioned by the Federal Ministry of Transport to conduct a short-term study on the green-arrow regulation. Within the framework of the research, the following investigations were carried out in the new federal states to study the advantages and drawbacks of the use of the green arrow sign as regards road safety and the capacity of signalized junctions equipped with the green arrow sign:

- accident investigations;
- observations of traffic conflicts and speed measurements;
- studies of event reconstructions;
- interview surveys of local authorities and drivers.

The research findings are mainly the result of the observations of traffic conflicts and interview studies.

Investigations

Accidents

On the whole, it was found that right turns on red at signalized junctions have not aggravated the accident situation in the GDR. Special safety studies have therefore not been undertaken.

As shown in Table 1, the number of accidents as a consequence of the green-arrow regulation permitting right turns on red is not a problem. Its maximum would correspond to the number of all right-turn-on-red accidents amounting to 1.1 per mill of all road accidents in the GDR between 1980 and 1989. The proportion of turning accidents of all junction accidents amounts to an average of 6.3 per mill.

The surveys conducted in Dresden and Berlin within the framework of this study confirm the low accident frequency. According to the information provided by the Dresden police department (traffic police division), the police recorded a total of 3,230 accidents in 1990 of which only four were right-turn-on-red accidents.

In order to arrive at statistically sound accident information, an analysis of accidents over a survey period of at least three years would be required. At the same time it would require that junctions with and
without the green arrow regulation be compared taking also the junction accidents in the old federal states into account.

Observations of traffic conflicts and speed measurements

The traffic conflicts technique is an often used method to assess potential high-risk situations on traffic facilities within a relatively short time.

Aside from interview surveys, the observation of conflicts provides an essential research basis in this context for the following reasons:

- exact and assessable data on right-turn-on-red are not available for the past years of the GDR
- new accident investigations would take too much time before yielding reliable evaluation data for this study.

A total of 13 junctions were selected in Dresden and Berlin taking the following different boundary conditions into account:

- urban location of junctions (new residential area, old residential area, housing development area)
- junction geometry
- type of signalization plan
- availability of a right-turn lane or shared right-turn and through lane
- volume of pedestrian traffic.

For the observation of conflicts, the junction space used by the right-turning vehicles, i.e. the critical conflicts area, was subdivided into three areas (cf. Fig. 2):

- conflict areas 1 and 2 to observe the conflicts due to right turns on red
- conflict area 3 in order to enable comparative research into right turns on green to be made.

During the observation of conflicts, the number of right-turning vehicles was surveyed, grouped by the vehicles entering the junctions on the red and green phase, respectively. In addition, counts were made of:

- number of pedestrians,
- number of vehicles crossing, and
- the number of opposing left-turning vehicles.

The surveys were conducted during peak hours and the other hours of the day in order to study not only the peak traffic loads during rush hours but also the high pedestrian volumes during business hours.
Results of conflict observations

The results of the observations in Dresden and Berlin differ so slightly that the following overall conclusions can drawn:

1. The number of right-turn-on-red conflicts observed, i.e. 105 conflicts in 62 hours of observation, is low in view of a total of
   - 10,138 right turns on red and
   - 2,242 confrontations with through and left-turning vehicles.

2. The total number of confrontations yields a slightly higher proportion of right-turn-on-green than right-turn-on-red conflicts:
   - On the red phase, 1,323 confrontations of cars and pedestrians resulted in 52 conflicts compared with
   - 88 conflicts in 1,184 confrontations of cars and pedestrians moving on the green phase.

3. Considering the fact that the true number of confrontations between cars and pedestrians is much higher than the number of confrontations shown in Tables 6 and 8--especially in the conflict areas 1 and 3 when cars meet with groups of pedestrians--the percentage share of conflicts is reduced even further.

4. The proportion of right turns on red of the total of right turns amounted on average to 51%.

5. In the case of extremely short green phases for right-turn movements at junctions with the green arrow regulation, the proportion of right turns on red increases to above 50%. This was the case at two junctions in Berlin where the proportion of right turns on red averaged 75% of the total of right-turn movements. Despite the relatively high traffic volume in the lane with the green arrow sign, the effective green time could be reduced to the advantage of the still higher volume of crossing movements because the volume of through movements--parallel to the right-turning vehicles--had been relatively slight.

6. Although only 2559 vehicles (about 25%) stopped on red before conflict area 1--several vehicles having to stop more than once--disciplined driving behaviour was observed in most cases. This is confirmed by the high proportion of slowly moving vehicles of approx. 85% of all right turns on red.
The speed measurements confirm these findings, as explained below.

Whether or not the volume of the conflicting streams of vehicles and pedestrians affected driving behaviour in any way could not be ascertained on account of the small number of junctions observed.

Based on the conflict observations, it can be concluded that the green-arrow regulation at the junctions observed did not have any additional detrimental effects on safety.

Results of speed measurements

The speed measurements on two junction approaches resulted in significant differences in mean speeds, both on the red and the green phase (statistical certainty of 99%).

About 30 m before the crosswalk the vehicles intending a right turn on red moved about 5 km/h slower than those making right turns on green; on the crosswalk itself they moved 3 - 4 km/h slower than on the green phase.

About 30 m before a crosswalk in a street with a speed limit of 50 km/h, a mean vehicle speed of 32.8 km/h was measured and in a street with a speed limit of 60 km/h 35.3 km/h. Calculations show that vehicles moving at these speeds are able to stop in time, even at the sudden appearance of pedestrians on the crosswalk.

Interview surveys

In order to obtain information on the experience acquired with the use of the green arrow plate, 28 state highway authorities, the highway authorities of 26 self-governing towns, and 15 police departments were questioned.

On the whole, the answers of six of the authorities revealed a negative attitude towards the green-arrow regulation, five were neither negative nor positive, and 57 positive in their attitude towards this regulation. The replies were weighted based on the frequency of use of the green arrow sign in each case. The research findings can be summarized as follows:

- Only few accidents were reported.
- The assumption of additional risks has been rejected more often than confirmed.
- For the majority of the junctions concerned, the parties interviewed expected large problems if the green arrow plates were to be abolished--including permanent tailbacks and land-use problems in the case of junction upgrading.
Criteria for use

The green arrow regulation requires increased attention on the part of all turning vehicles and the observation of the right-of-way of crossing pedestrians and vehicles. Green arrow plates may only be used if the right-turning vehicles moving on the red phase can fulfil their obligations. This is to say that they must be able to grasp prevailing conditions as well as foreseeing impending changes or possible risks. If unusual flow conditions remain unclear to them, they should be avoided.

In addition, the green arrow regulation should only be used if it can be expected to effect the necessary increase in throughput or substantially reduce congestion or additional stopped delays.

Conditions justifying the green arrow regulation

- The green arrow regulation is appropriate when:
  . a separate (additional) right-turn lane is permanently congested, i.e. it is too short
  . right-turning vehicles are blocked by pedestrians (conflict area 3)
  . vehicles making a right turn on green block the lane for the through vehicles behind them.

- The green arrow regulation may be applied:
  . if right-turning vehicles merge with a coordinated traffic stream (linked traffic lights)

Conditions not justifying the green arrow regulation:

- The green arrow regulation should not be applied when the following conditions prevail:
  . frequent presence of waiting left-turning bicycles on the lane where vehicles line up to make right turns (pursuant to Section 9, para 2, of the German Highway Code, left-turning bicycles are permitted to cross the roadway behind the junction, proceeding from the right-hand side of the street)
  . exclusive turning phase for the opposing left-turn flow
  . poor sight conditions (e.g. if due to the oblique geometry of a junction right-turning vehicles do not have a clear view of the crossing through vehicles changing over to the right-hand lane or if on a multi-lane approach the view of pedestrians on the crosswalk approaching from the left-hand side is blocked by the presence of trucks or
busses on the neighbouring lane; in that case extending the right-turn lane further back would improve the situation.)

- frequent presence of persons with impaired vision at a junction where additional acoustic signals are not sufficient for orientation (persons with impaired vision get their orientation from the tire noise; the noise of right-turning vehicles moving on the red phase is a source of irritation. These problems have to be solved separately for each single case in question, taking the use of additional acoustic signals into consideration).

- Conditions prohibiting the use of the green-arrow regulation:
  . frequent accidents or incidence of severe accidents
  . permitted turning phase for the opposing left-turn flow
  . presence of tramway rails which have to be crossed.
Markings
an Important Visual Guidance System in Europe

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abstract:

Markings, an important visual control system in Europe!

Roads with markings are taken for granted by motorists in Europe, they are part of the familiar scheme of things.

Marking symbols are used to indicate or legally prescribe specific behaviour on the road, on the basis of European legislation in the area of road traffic. This "sign language" is not exactly the same all over Europe, however, it is very similar and comparable, so that problems of comprehension almost never occur. Markings are used to give visual guidance, to control traffic and, therefore, they make an important contribution to promoting the flow of traffic, to influencing behaviour on the road and making the presence of other motorists and encounters with them more safe.

Not only the correct geometry of the markings, i.e. their application and method of presentation on the road, but also the materials selected are of vital importance. Markings are only effective as a visual control system if they are sufficiently durable, non-slip and visible. They must be in a fully functioning condition both by day and by night and in the new and used state. There is a comprehensive system of national technical regulations which exist for this purpose.

Night visibility is of particular importance; only if this requirement is satisfied is it possible to guarantee day-night uniformity.

Markings are an indispensable part of the roads. They are just as important as the grip and smooth surface of carriageways, traffic signs and safety devices. For this reason, it is of decisive importance for the purpose of visual guidance and, therefore, for traffic safety and the control of traffic, that markings are used which are easily visible during the night and whose effectiveness is permanently assured. Only in this way are they able to exert their positive influence as a visual control system during the day and night on the European roads.
INTRODUCTION

The marking of roads has been customary in Europe since approximately 1920. It began in the USA where markings were applied to the middle of the carriageway for the first time around 1911; they developed initially in Europe and finally throughout the whole world. Today they have become so much part of the road that it is hard to imagine a world without them today. It would be impossible to achieve a safe and flowing control of traffic without markings. There is no doubt whatsoever about their significance for road traffic today.

Marked roads are taken for granted by motorists. Markings have become such a familiar sight on roads that it is their complete absence, for example, after the resurfacing of a road, or their lack of visibility during the night and under wet conditions, which becomes noticeable. The excellent visual guidance system offered to road-users by markings is what I would like to make the subject of my talk. At the same time, my concern is to make it clear that this guidance system can only fulfil its purpose if it remains fully operational at all times, during the day and at night, as well as in sunny and rainy weather.

International harmonisation of the design of road markings began with the Vienna Convention on Road Traffic of the United Nations of 1968. This lays down the basic marking symbols. In 1973, the countries belonging to the European Conference of Ministers of Transport (ECMT) passed the "European Rules concerning Road Traffic, Signs and Signals", which also contain a chapter on road markings.

Although it is not identical, the "sign language" of markings in the different countries of Europe is very similar and comparable as a result. The freedom in design granted to national regulations by the European Rules is, however, not so great that the marking symbols or their practical use could lead to difficulties of comprehension or even a lack of comprehension. Therefore, it is sufficient if I limit myself essentially to German examples when explaining the European visual guidance system of markings.

PURPOSE OF MARKINGS AND HOW THEY WORK

Markings are visual signals just like traffic signs which are aimed at motorists [1]. They are intended to provide assistance to motorists help them find their direction and make progress, lead them to a mode of behaviour in traffic which promotes the flow of traffic as well as to render the coexistence of, and encounters with others more safe. [Fig. 1].
The marking symbols themselves, the modules which make up the markings which motorists are faced with on roads, must be very simple and comprehensible. Only then can they be "subconsciously" understood by road-users. It is easier to induce correct behaviour on roads by means of markings than by using traffic signs, even in the case of those road-users who consciously disregard existing rules.

Three general characteristics of markings are especially advantageous.

1. They permanently accompany the driver throughout his journey so that he is not forced to try and remember them, as in the case of traffic signs [Fig. 2].

Comment:
Fig. 2 demonstrates this very clearly. You can see the traffic sign "No overtaking" which is standing isolated on the right side of the road and which is easily forgotten, while the one-direction no-passing marking continues to be the constant companion of the motorist far beyond this point.

2. As a result of the good contrast between the white of the markings and the darker road surface, they are normally very easily seen.

3. In the dark, they are directly in the range of the headlights.

In Germany, for this reason all areas outside towns should be marked both at the edges of the carriageway as well as in the middle. [2] I will return to this point later.

3 MARKING SYMBOLS AS A VISUAL GUIDANCE SYSTEM

Even if it may seem very trite to you, I ask that you permit me to take three examples from the sign language of longitudinal markings to demonstrate the intelligence and simplicity of this visual guidance system. It is not really necessary to learn the system, it is understood without requiring any initiation, something which cannot always be said for other guidance systems.

1. Continuous lines may not be crossed

2. Broken lines may be crossed.

3. If continuous and broken lines are situated parallel to each other, vehicles from the side on which the broken lines are situated may cross the continuous lines to the other side [Fig. 2].

As Fig. 2 shows, there is no problem in presenting this scheme on the road and it is easily understood. We could dispense with erecting the traffic sign indicating the ban on overtaking if it were possible to ensure the markings were recognisable and visible at all times. Were the carriageway
completely covered, for example by a layer of snow, this would no longer be the case.

At this point I would like to show you, by means of two photographs, a difference between markings in France and markings in Germany - a difference which is not likely to present any problems to road-users. In Fig. 3, you will see an edge line on a German motorway (Autobahn). The rule in Germany applies that edge markings must be made in the form of thick strokes if there is a hard verge beyond them of more than 1 metre in width, in this case a hard shoulder. These thick strokes are able to be crossed over in certain circumstances, in contrast to the thin strokes. Fig. 4 shows the marking in front of a hard shoulder on a French motorway. You can see that there are only brief "interruptions" here, "legal" openings which allow driving on the hard shoulders. French colleagues have confirmed my suspicion that French drivers, even in Germany, would not hesitate to use the hard shoulders in an emergency - even without these "openings".

Directional arrows in lanes indicate in which direction one may or must drive. Warning arrows indicate how and where additional lanes end or, for example, at which stage overtaking must either have been completed or no longer begun.

In conjunction with warning lines, that is to say the broken longitudinal markings with reversed stroke-space ratio which mark the transitional element or linking element between broken and continuous centre lines [Fig. 5] an excellent instrument of visual guidance has been created in the run-up to hills and curves where there is a lack of visibility [Fig. 6]. The length of the warning line must depend on speed and the number of the warning arrows must be restricted to a maximum of three.

The time remaining to me for my speech does not permit me to deal with the topic of the guiding system of markings in all its detail. For this reason, I would like to conclude this part of my speech with a few comments on the longitudinal markings on secondary roads.

In Germany, as I already said at the beginning, roads outside built-up areas always have markings at the edges of the carriageway as well as in the middle. Inside built-up areas, pavement borders replace the markings. Whether or not longitudinal markings are actually put in the centre of the carriageway depends very much on the level or frequency of traffic, and any decisions in this respect should be made from aspects of road design and of reduction of speed on main roads through towns. Road junctions on main roads should never be left unmarked!

Outside towns, edge lines should always be marked [Fig. 7]. Whether centre lines are marked depends on the width; the limit is 5.50 metres. Fig. 8 shows the transition from a road of sufficient width to a narrow street.

The lack of the centre lines gives road-users a very clear indication of the reduced width and the edge lines also indicate up to which point they may drive. It is wrong to mark narrow streets only in the middle, as shown in Fig. 9, even if it does result in considerable savings in marking materials.
Markings at the edge of the carriageway are more important for visual guidance than markings in the middle. Motorists receive their orientation to a very great degree from the edge lines. [Fig. 10]. The distance maintained from the side of the road is greatly influenced by the edge lines, especially in the dark.

Marked edges also help to reduce the expenditure on maintaining verges, as these are less often driven over and damaged since vehicles which move out to the side to avoid oncoming traffic are more easily able to recognise the borderline of the hard surface.

It still remains to be said that markings considerably influence the characteristics of a stretch of road. The geometry of the markings should, therefore, be restricted to the same type as far as possible, even beyond administrative boundaries.

4 VISUAL GUIDANCE AND ACCIDENTS

Road-users should be informed of expected behaviour or desirable behaviour by the course or impression of the roads themselves and additionally by visual aids to guidance.

However, there are many points in the network of roads where the characteristics of the road itself do not induce each road-user to select the correct speed for the circumstances. Unchanged speed leads to many road accidents, either as a result of wrong estimation of alignment or of recognising danger points too late. Equally important are the condition of the carriageway, the time of day and the weather conditions. Improvement of visual guidance through the use of visual control systems is required just as much on both old and new roads, in order to avoid at least some accidents. [3]

According to surveys done by the German Federal Highway Research Institute, the most common type of accident which occurs at night is the "driving accident" ("driving accident" refers to an accident in which the driver loses control of his vehicle but not due to to a conflict with another road-user). 90 % of these driving accidents occur outside towns on curves on wet or slippery roads. Car accidents at night weigh particularly heavily as they account for approx. 43 % of all persons killed in cars and approx. 40 % of all severely injured persons in cars. [4]

The accident rate at night is three times higher than the rate during the day. Given that wet road conditions only exist 10-15 % of the time, the fact weighs especially heavily that the most frequent characteristic to cause accidents, accounting for approx. 30 %, is wet conditions at night.

At this point, I must once again quote Domhan who had summarised these aspects in one sentence while speaking about the problems of visual guidance at night and under wet conditions. [5]
Quote:

"The most unfavourable case with regard to visual guidance is when a single vehicle is travelling at night under wet conditions along an unlit, single-lane road with bends and with occasional oncoming traffic."

5 NIGHT VISIBILITY

I had mentioned at the beginning that the visual guidance system of markings not only has to fulfil its purpose during the day and in sunshine but above all at night under wet conditions.

But fulfilling this purpose in particular is especially difficult. On wet roads, the markings are covered by a film of water which greatly restricts or cancels out the reflective properties. Fig. 11 shows the path of rays of a glass bead, i.e. the process of retroreflection in which the ray of light is reflected back to the source. In Fig. 12, the glass bead is covered by a film of water so that the ray of light cannot penetrate and it is mirrored, i.e. is diverted away from the observer.

It is already very difficult to guarantee the night visibility of markings throughout their whole life on the road in dry conditions. In contrast to traffic signs, which are exposed only to weathering and ageing, markings are driven over and worn down by motor vehicles.

Nevertheless, there is a large number of marking materials able to cope with such stresses and which also satisfies traffic engineering requirements: day and night visibility and skid resistance as well as the demands on durability and environmental protection and work safety.

Comprehensive technical regulations for the purpose of quality assurance exist in the European states. In the future, European standards will apply instead of national regulations. These European standards also contain specifications and test procedures for markings with increased night visibility under wet conditions.

Luminous guidance of vehicles is essentially influenced by the distance required before the markings are recognised. [8] This distance is reduced to approx. 1/4, that is to say 10 - 20 metres as a result of wet conditions in the case of the conventional new markings. The direction of visual fixation, however, lies not only at close range but also to 90 % at long-range. [Fig. 13]

As a result of the development of markings which, in contrast to the conventional markings, have no smooth surface but instead graduated, wave-shaped or dot-shaped raised sections, it was possible to achieve a condition whereby the headlights penetrated the glass bead in spite of the film of water and the light could be reflected back to the eye of the driver. [7] Fig. 14 demonstrates the underlying principle.

With markings shaped in this way, it was possible to realise recognition distances under wet conditions of approx. 80 metres. [8]
There has been considerable progress made in the meantime in the development of new products with better visibility under wet conditions made of all types of materials - paint, hot plastic, cold plastic or tapes. It is hoped that administrations will be given sufficient financial scope in future to allow them to make increasing use of such markings - given their importance for traffic safety.

I say this not least because I am convinced that the night visibility of markings will have even greater significance in future. I can already say now that I believe this to be the most important characteristic of markings.

According to current estimations, approx. every fifth German will be over the age of 60 years by the end of the century. Senior citizens already account today for a high number of those killed on the roads, at a rate of approx. 20%.

6 SIGNIFICANCE OF MARKINGS FOR OLDER MOTORISTS

Powers of vision reduce with increasing age, however, without this being necessarily obvious in many cases to those affected. These age-related impairments of vision, that is to say, increasing sensitivity to glare, deteriorating visual acuity in twilight and, finally, reduced visual acuity in daylight, are accompanied by an overall reduction in physical and mental ability.

Brüning and Harms [9] have ascertained that the accident risk for older drivers at night in deteriorating weather conditions and conditions of visibility is increasing at a higher rate than for the comparable group of 30-40 year old drivers.

The luminance to which the eye has become accustomed, the adaptation luminance, influences visual acuity. Soiling of windscreens and headlights, shaded eyeglasses and shaded windscreens are other contributory factors.

On the other hand, we should not fail to mention that with older drivers there is also a useful compensation for their age-related weaknesses, for example, resulting from the fact that journeys under unpleasant conditions are avoided, that the journeys made are shorter in length and that less risks are taken while driving.

Older people tend more and more to avoid driving in the rush hour and tend to have their eyes tested more and more frequently. [10] However, optical aids (spectacles) can only partly compensate for the reduction in visual acuity which arises through the change in the optical image formation in the eye, whereas the age-related clouding of the eye, which results in increased sensitivity to glare, cannot be compensated for.

The degree of recognition of road markings, primarily during the night, is directly linked to these factors of influence. This is why I consider it so important to deal with the connection between sight and age in such detail.
The change in the average age of road-users, to say it once again, the fact that every fifth German will be over 60 years of age by the end of the century, should be reason enough to aim for further improvement in visual guidance.

I have already emphasised the significance of markings for visual guidance on roads outside built-up areas. I would also like to highlight their value for managing driving situations beside road junctions, in particular at complex urban intersections. I shall use an illustration [Fig. 15] from the German guidelines for road marking applicable in Germany (RMS-2) as an example of this type of situation. [11]

Older motorists in particular have problems at crossroads and junctions. The importance of separating off the traffic areas using easily visible markings is, in my view, undisputed.

7 CONCLUSION

I would not like to end my speech on the - in my opinion - almost inexhaustible subject of "road markings" without taking this opportunity to ask you to lend your support in ensuring that more attention is paid to this inherently cheap visual guidance system throughout Europe. It makes sense, for economic reasons, to call for action when markings are lacking or are in bad condition, to remedy this situation. The cost-benefit ratio of markings is extremely high. Expenditure on markings is extremely low compared to other road fittings or the construction of roads themselves; this also applies to the still relatively expensive markings with increased night visibility under wet conditions.

Traffic safety in Europe, the subject-matter of this Congress, cannot be guaranteed without the use of markings!

Markings are and will continue to be of decisive importance for traffic safety and are indispensable for this reason. Their importance is equal to that of grip, smooth road surfaces, traffic signs and safety devices. Unfortunately, their significance is frequently underestimated and markings are not always used in such a way as to allow them to exercise fully their positive effects on the control and safety of traffic.

I would be very happy indeed if I succeeded, with my contribution, in showing that markings, as a visual guidance system in Europe which is understood beyond all language barriers, offer the chance to promote traffic safety and efficiency of roads for the benefit of all. I repeat what I said at the beginning of my speech - that this important visual guidance system can only fulfil its purpose if it remains fully operational at all times, that means especially able to be recognised and be visible during the day and night, in sunny and rainy conditions.
BIBLIOGRAPHY


Fig. 1: Markings for visual guidance in road traffic.

Fig. 2: Country road with markings at the edges of the carriageway and in the middle of the carriageway.

Fig. 3: Edge line in front of a hard shoulder of a motorway in Germany.

Fig. 4: Edge line in front of a hard shoulder of a motorway in France.
Leitlinie 1:2:1

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<thead>
<tr>
<th>8 m</th>
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<td>2 m</td>
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Warnlinie 2:1:2

Fig. 5: Geometry of broken white lines and warning lines.

normal befahrene Landstraßen \( V > 70 \text{ km/h} \)

\[ \text{Md.L.: Md.B = 5:3} \]

langsam befahrene Landstraßen \( V \leq 70 \text{ km/h} \)

Stadtstraßen

Fig. 6: Length of warning lines and position of warning arrows on stretches of roads without intersections (RMS 2, Fig. 26)

Fig. 7: Narrow road without centre lines.

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Fig. 8:
Transition from fully marked, sufficiently wide road with oncoming traffic to a narrow street (width < 5.50 m)

Fig. 9:
Wrongly marked narrow street.

Fig. 10:
Markings at the edge of the carriageway are more important for purposes of visual guidance than markings in the middle of the carriageway.
Fig. 11: Retroreflexion through glass beads.

Fig. 12: Obstruction of retroreflexion through film of water on glass beads.

Fig. 14: Maintaining retroreflexion through the shaping of the marking even when it is covered by film of water.
Fig. 13:
90% direction of visual fixation of motorists with dipped beam headlight on a straight road.

Fig. 15:
Markings of intersection areas at widened road junctions (RMS 2, Fig. 39)
Traffic Safety Related to Types of Road and Traffic Signals

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TRAFFIC SAFETY RELATED TO TYPES OF ROAD AND TRAFFIC SIGNALS

The Gdansk conurbation (a population of 820000) has two harbours (Gdansk and Gdynia) with the ferry and container terminals. In this conurbation the north entrance to the Transeuropean Motorway TEM is planning. At last two years the number of cars increased about 20%, and simultaneously the increase of accidents overpassed the increase of traffic. The severity of accidents increased too and remains at an unacceptable high level.

Some factors effecting this low traffic safety are investigated in the Highway Engineering Department of Gdansk Technical University. In the paper, the influence of cross-section elements (number of lanes, width of pavements, type of shoulders), the density of intersections and traffic signals on safety are presented. Also, the first remarks on the driving on lights during the daytime in Poland are mentioned. The research works were carried out on the road network in Gdansk province.

VTI RAPPORT 380A
1. INTRODUCTION

Until now the traffic safety research in Poland were carried out partly and in a very narrow scope in spite of several important and specific for our country, for example: a lot of pedestrians, high percentage of heavy vehicles in traffic flow, high percentage of two-lane rural highways. At last two years the number of cars increased about 20% and simultaneously the increase of accidents overpassed the increase of traffic. The severity of accidents increased too and remains at an unacceptable high level.

Some factors effecting this low traffic safety and concerning urban and rural highways were investigated at the Highway Engineering Department of Gdansk Technical University. In the paper, the influence of cross-section elements (number of lanes, width of pavements, type of shoulders) and traffic signals on safety in Gdansk Region are presented.

2. CROSS-SECTION AND TRAFFIC SAFETY

2.1. General

The statistics of traffic accidents in Poland show, that about 55% of road accidents occur on the straight road section. The main kind of accidents are as follow: collision of vehicles in traffic, moving obstacles, running into obstacles, running into pedestrians and overturning the vehicle. Traffic participants are blamed in police reports in more than 95% of events, giving the following reasons: excessive speed, incorrect overtaking, by-passing and passing, driving the wrong side of the road, vehicle slip, etc. Blaming for the road events only because of the participants, causes, that a less attention is paid to a real influence of the road, as a direct reason of many of these events. As is shown at foreign research results, the blame can be directly attributed to the drivers' fault in real situation only in 30-50% events, but in the remaining causes the factors connected with the road and traffic are fundamental [1]. In a case of straight road section, the main factors influencing traffic safety are the cross-section elements of the road, and first of all, roadways, shoulders, median, slopes, ditches and structures. In 1989 the research of influence of the chosen road cross-section elements on traffic safety has started at the Technical University of Gdansk [2].
Two main indicators were taken to analyse:
- density of traffic accidents:
  \[ DTA = \frac{NA}{L \cdot n} \]
- traffic accident cost:
  \[ TAC = \frac{TTAC}{L \cdot n} \]

where:
- \( NA \) - number of road accidents, [acc./year],
- \( TTAC \) - total traffic accident cost [mln zl/year],
- \( L \) - length of the analysed road section, [km],
- \( n \) - number of lanes in a cross-section of the road.

2.2. Urban area

Seven main chosen arteries of traffic in Gdansk, of about 65 km length, divided into 27 sections, different in respect of cross-section and volume of the road and pedestrian traffic were investigated. The influence of traffic volume, pedestrian volume, number of lanes and existence of median on density of accidents and their costs.

On the base research results it can be stated, that the density of traffic accidents \( DTA \) (accidents per 1 km and one lane), mainly depends on the

<table>
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<tr>
<th>Type of cross-section</th>
<th>Density of traffic accidents (acc/km/lane/year)</th>
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\[ ADT = 5000 \text{ veh/lane/day} \]

![Fig.1. Density of traffic accidents DTA versus pedestrian volume PT and types of cross-section at urban area.](image)
volume of the road traffic ADT and on the volume of pedestrian traffic PT and grows simultaneously with the increase of these values. However, the more lines, the safer streets (fig. 1).

In the case of the analysis of traffic accident results, represented by traffic accident costs TAG (fig. 2), the characteristics of these relationships are different and TAC is inversely proportional to a pedestrian traffic PT. It is a result of the fact, that the most dangerous accidents occur on streets, where the volume is low and vehicles can be driven with relatively high speed. The relationship between the traffic accident costs TAC and the traffic volume ADT has got an optimum while volume is about 5000 veh/lane/day. The above indicates, that for a low volume, in spite of the number of accidents is lower, their results are more dangerous (high speed). However, simultaneously with the increase of volume the number of accidents increases too, but their consequences are less dangerous.

2.3. Rural area

<table>
<thead>
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<th>ADT = 5000 veh/lane/day</th>
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<tr>
<td>PT &lt; 100 P/h</td>
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<td>TAC (min z/km/lane/year)</td>
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<td>18</td>
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<td>15</td>
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<td>12</td>
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Type of cross-section

Fig. 2. Traffic accident costs TAC versus pedestrian volume PT and types of cross-section at urban area.

The main road, situated on the Gdańsk Region area, 1780 km of total length, divided into 54 section, different in respect of cross-section parameters and volume were investigated.

The influence of traffic volume, number of lanes, the width of the road and type of shoulders, the density of road accidents were examined. On the of the results it is possible to state, that the density of traffic accidents DTA depends mainly on traffic volume ADT and type of cross-section. The density of traffic accidents grows simultaneously with the increase of the volume ADT. On the
On the roads with median, two times fewer accidents occur on one lane and 1 km of the road, than on the roads without median (fig.3).

\[ ADT = 5000 \text{ veh/lane/day} \]

<table>
<thead>
<tr>
<th>Width of the road PW [m]</th>
<th>Density of traffic accidents DTA (acc/km/lane/year)</th>
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<tr>
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</tr>
<tr>
<td>7.5 + 2 x 2</td>
<td>0.80</td>
</tr>
<tr>
<td>9.0</td>
<td>1.00</td>
</tr>
<tr>
<td>2 x 7.0</td>
<td>1.20</td>
</tr>
</tbody>
</table>

Fig.3. Density of traffic accidents DTA versus types of cross-section at rural area.

3. TRAFFIC SIGNALS

Traffic control measures are used at intersections where traffic volumes are sufficiently large and/or where accidents rates are undesirably high. A review of research of a large nationwide accident data base led among others to the following conclusions [3]:
- signalisation leads to a reduction in right-angle accidents and increase in rear-end accidents,
- signalized intersections have higher accident rates with less severity per accident,
- the right-angle accident rate seems to be better than the number of these accidents for the improvement evaluation.

Usually accident rates at T-intersections are markedly less than those at cross-intersections. But in many cases, this is not evident, that the installation of signals will reduce the adverse effects of accidents, especially, where signals would not be warranted. Real changes in accident rates and percentage of accident types depend on the local road-traffic conditions and kind of statistical analyses.
The problem mentioned above was investigated at chosen intersections in Gdansk. Two analyses were carried out:
- the general comparison of accident rates for 86 unsignalized and 51 signalized intersections; accident data concern 1984-1991 period,
- the detailed comparison of accident rates and types of accident for 12 intersections before and after the signal installation; 1-3 years periods are compared.

Table 1  Variation of Accident Rates with Intersection Geometry and Traffic Control in Gdansk

<table>
<thead>
<tr>
<th>Geometry</th>
<th>Trafic Control</th>
<th>Pedestr. Volume</th>
<th>Accident Rate*</th>
<th>Accident Cost Rate**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cross</td>
<td>Signals</td>
<td>&lt; 1000</td>
<td>0.29</td>
<td>0.26</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 1000</td>
<td>0.38</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Signs</td>
<td>&lt; 1000</td>
<td>0.23</td>
<td>0.21</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 1000</td>
<td>0.28</td>
<td></td>
</tr>
<tr>
<td>T- Intersection</td>
<td>Signals</td>
<td>&lt; 1000</td>
<td>0.12</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 1000</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Signs</td>
<td>&lt; 1000</td>
<td>0.10</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 1000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* - accidents per milion vehicles
** - accidents cost per milion vehicles

The general comparison is similar to those from other studies of the same nature (Table 1). Accident rates are a little higher at signalized intersections, especially at cross-intersections. It results from characteristics of these intersections (Table 2). Accident rates of cross-intersection are twice as much as at T-intersections.

Table 2  Characteristics of Investigated Intersections

<table>
<thead>
<tr>
<th>Type of control</th>
<th>number of legs</th>
<th>daily volume</th>
<th>number of crossings</th>
<th>by-street traffic %</th>
</tr>
</thead>
<tbody>
<tr>
<td>signals</td>
<td>3.7</td>
<td>33000</td>
<td>3.2</td>
<td>18</td>
</tr>
<tr>
<td>signs</td>
<td>3.0</td>
<td>22000</td>
<td>1.8</td>
<td>11</td>
</tr>
</tbody>
</table>

The comparison in "before - after" analyses (Table 3) shows that after the signal installation:
- the number of accidents remains on the same level,
- percentage of accident types like rear-end and right-angle increase approx, two times, especially at cross-intersections
- percent of accidents with pedestrians decreases of about 30%.

**Table 3** Variation of Accident Type with Intersection Geometry before and after Signals Installation

<table>
<thead>
<tr>
<th>Geometry of intersection</th>
<th>Number of accidents</th>
<th>Accident Type Percent of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>rear-end</td>
</tr>
<tr>
<td>before</td>
<td>cross T</td>
<td></td>
</tr>
<tr>
<td></td>
<td>26</td>
<td></td>
</tr>
<tr>
<td>after</td>
<td>cross T</td>
<td></td>
</tr>
<tr>
<td></td>
<td>23</td>
<td></td>
</tr>
</tbody>
</table>

**Table 4** Effect of Signal Installation on Accident Severity

<table>
<thead>
<tr>
<th>Geometry</th>
<th>Number of accident</th>
<th>Injury and Fatal Accidents Percent of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>before</td>
<td>cross T</td>
<td>54</td>
</tr>
<tr>
<td></td>
<td>26</td>
<td></td>
</tr>
<tr>
<td>after</td>
<td>cross T</td>
<td>48</td>
</tr>
<tr>
<td></td>
<td>23</td>
<td></td>
</tr>
</tbody>
</table>

Also, the percent of injury and fatal accidents decreases of 26% at cross-intersections and 40% at T-intersections (Table 4).

4. **CONCLUSIONS**

The results of the research described above indicate that the road cross-section elements have an essential influence on the state of traffic safety. It is possible to get a considerable improvement of traffic safety with regard to the traffic safety problems during the process of road designing or their maintenance.

The study of accidents at Gdansk intersections confirms the results of other studies. Usually the signal installation doesn't reduce the number of accidents, but changes the percentage of accident types. In Polish conditions, the signalisation leads to considerable of injury and fatal accidents.
REFERENCES:


Route Choice Behavioural Models Analysis of a Route Guidance System for a Congested Urban Area (II)

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ROUTE CHOICE BEHAVIOURAL MODELS ANALYSIS
FOR THE REALIZATION OF A ROUTE GUIDANCE SYSTEM
FOR A CONGESTED URBAN AREA

ABSTRACT

Route Guidance System is a technology developed for facing efficiently traffic problems in congested urban areas.

Final goals of our research are a study and a step by step accomplishment of an Expert System prototype in order to simulate an on-vehicle Information System behaviour with the following characteristics:
- route choice according to the personal user criterion;
- capability of managing sudden critical situations (congestion, accidents, work in progress) by showing real-time alternatives routes on the surrounding network;
- route choice according to the on-board disposability of an Information System, perfectly updated about the road network conditions and other user services as parking availability.

Current steps already developed are:
- Analysis of the most recent Control and Regulation techniques.
- Analysis of effectiveness of an information system to be introduced in the city of Rome.
- Multi-criteria scenario, for the choice of the best route.
- Driver behaviour under multi-criteria conditions and application with the Keeney model.
- Models of decisional structures of the driver Saaty model.
- Problems relating to trip chaining and Route Guidance Systems.

In a previous report, the main features of information systems for road users, especially of route guidance systems, have been described and an effort was made to point out the importance of the information of users both for the transportation system (reduction of travel times, increase in system efficiency) and for the user (rationality of journey choices, psychological benefits from the reduction of uncertainty of his own and other people's journey); steps a e b.

This report is instead dedicated to study a methodology for the analysis of the behaviour of road users in selecting a route so that it may be possible to define the main choice criteria; steps c-f.
The examination of a user's choice regarding the accomplishment of a journey has allowed to determine four main elements in the choice mechanism;

1) the time of choice, discriminating from the planning and the execution of the journey;
2) the choice criterion, i.e. the objectives the user means to satisfy in the accomplishment of his journey such as minimum costs and travel times, a comfortable journey, etc. All of this elements, each with a different weight, contribute simultaneously to the decision of the user;
3) the source of information, i.e. personal experience, indications given by the other people or by an information system;
4) the information processing system, i.e. partly the mind of the driver and partly the information system.

The problem can be approached in different ways: an analytical approach to study the choice mechanism with the aid of a mathematical model and an empirical approach that, through direct observation of actual behaviour, allows to define a regressive type model.

Once the phenomenon has been understood, the theoretical approach allows to interpret any situation that satisfies the assumptions made for the validity of the model. One methodology that has so far been used for the theoretical study of the behaviour of users in the route choice is the multi-criteria analysis that represents the process of compromises made by the user among various purposes and needs.

This methodology was applied with the Keeney and the Saaty models, even relating to trip-chaining approach.
1. INTRODUCTION

Route Guidance System is a technology developed for facing efficiently traffic problems in congested urban areas.

Final goals of our research are a study and a step by step accomplishment of an Expert System prototype in order to simulate an on-vehicle Information System behaviour with the following characteristics:
- route choice according to the personal user criterion;
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Current steps already developed are:

- Analysis of the most recent Control and Regulation techniques;
- Analysis of effectiveness of an information system for the city of Rome;
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- Driver behaviour under multi-criteria conditions and applications with the Keeney and the Saaty models;
- Models of decisional structures of the driver;
- Problems relating to trip chaining and Route Guidance Systems.

In previous reports (see Gori, Carrese, Fusco 1991a), the main features of information systems for road users, especially of route guidance systems, have been described and an effort was made to point out the importance of the information of users both for the transportation system (reduction of travel times and increase in system efficiency, e.g. in the case of the feasibility study on the Roman network) and for the user (rationality of journey choices, psychological benefits from the reduction of uncertainty of his own and other people's journey); steps a and b.

The driver behaviour problem may be approached in different ways: an analytical approach to study the choice mechanism with the aid of a mathematical model and an empirical approach that, through direct observation of actual behaviour, allows to define a regressive type model. One methodology that has so far been used for the theoretical study of the behaviour of users in the route choice is the multi-criteria analysis that represents the process of compromises made by the user among various purposes and needs. This methodology was applied with the Keeney and the Saaty methods (see Gori, Carrese, Fusco 1991b); steps c and d.

In this report are considered a more advanced approach of the choice problem, introducing an aleatory component in the behaviour of the user and the presence of a combination of multiple destinations (trip chains); steps e and f. A broader treatment of the subjects discussed in this article is contained in Carrese, Fusco and Gori (1992).
2. **ANALYSIS OF ROUTE CHOICE BY ROAD USERS**

When planning a journey, a driver must take decisions on departure time, mode of transportation, route to follow. These decisions are taken in two different phases: in the planning phase decisions are made before the journey starts about departure time and mode of transportation; choices about the route to follow are made both before and during the journey: this is the execution phase. The user processes available information on the basis of personal experience making decisions on the journey according to a choice criterion of his own. The examination of a user’s choice regarding the accomplishment of a journey has allowed to determine four main elements in the choice mechanism:

1) the time of choice, discriminating from the planning and the execution of the journey;
2) the choice criterion, i.e. the objectives the user means to satisfy in the accomplishment of his journey such as minimum costs and travel times, a comfortable journey, etc....
   All of this elements, each with a different weight, contribute simultaneously to the decision of the user;
3) the source of information, i.e. personal experience, indications given by other people or by an information system;
4) the information processing system, i.e. partly the mind of the driver and partly the information system.

The study of the behaviour of users in the route choice can be approached in different ways: an analytical approach to study the choice mechanism with the aid of a mathematical model and an empirical approach that, through direct observation of actual behaviour, allows to define a regressive type model.

The empirical approach has been followed, for example, to study the behaviour of drivers in the face of congested situations that usually occur at certain points of the network and that are due to disturbing phenomena such as, for example, children coming out of a school (see Duffel and Kalombaris 1988). As was remarked, in this case drivers on a regular journey leave the main route for a longer, more tortuous but quicker route. This behaviour has been named “rat running”. The behaviour of drivers has been observed and related with the answers, given in a questionnaire, on the most important choice criteria (route length, travel time, degree of congestion that has been met). A regressive model was built to relate the percentage of drivers that leave the main route with the values of the quantities that represent the various choice criteria. This type of approach allows to determine, with a simple enough procedure, a relationship to explain the phenomenon and furthermore allows to estimate, through the regression index and statistical tests, the degree of adhesion to reality of this relationship. At the same time there is the great drawback that it is not possible to generalize the relationship, if not but qualitatively and with due caution to a situation different from that on whose direct observation the relationship was obtained.

Instead once the phenomenon has been understood, the theoretical approach allows to interpret any situation that satisfies the assumptions made for the validity of the model. One methodology that has so far been used for the theoretical study of the behaviour of users in the route choice is the multi-criteria analysis.

Multicriteria analysis is a methodology used to choose from a number of alternatives, such as in this case possible routes, accepting the existence of a multiplicity of objectives that may even be contradictory and inexpressible with cardinal measures. This procedure determines a hierarchy among the various objectives and allows every single point of view to participate in the choice process. In the planning phase and during the journey, the user selects from several possible routes the one he reckons best according to a number of objectives he has set. Road users cannot be regarded as wholly and homogeneous since there are complex choice mechanisms with objectives that can even be contradictory. It is not possible to satisfy at the same time a multiplicity of objectives...
and thus multicriteria analysis does not provide an optimum solution but can only help to approach one.

3. BEHAVIOURAL MODELS FOR ROUTE CHOICE

The construction of behavioural models to interpret users' choice of transport system has hitherto been conducted following two categories of models, aggregated and disaggregated. Aggregated models can be used to interpret the behaviour of road users as a whole, but cannot be used to formulate the problem of choice from the individual point of view. Disaggregated models, on the other hand, describe the behaviour of the individual by means of discrete variables.

The earliest applications of disaggregated models in transport refer to the problem of modal choice between two alternatives (binary choice models). Later, the theory of choices was extended to the problem of multiple discrete alternatives (multinomial choice models): it was thus possible to treat, in addition to choice among several alternative modes, such other problems as destination choice or route choice.

In disaggregated choice models, the object of study is the smallest unit that enters into the choice process, in this case the road user.

The components of a disaggregated choice model are:
1. the decision maker;
2. the set of choice of alternatives;
3. the attributes of the alternatives;
4. the rule of decision.

The decision maker is the author of the choice process. For route choice, the decision maker is the road user.

Each decision maker's choice set consists of the possible alternatives for the individual user. An alternative is made possible by such conditions as: physical availability, user awareness, economic and time availability of the user.

Each alternative in the choice set is characterized by a series of attributes that define the degree of user satisfaction.

The choice among a set of alternatives requires a rule of decision that describes the user choice mechanism. Generally three types of rules of decision are considered:
- dominance: one alternative is dominant over another if it is better in at least one attribute and not worse in other attributes; in most cases, this rule does not permit reaching a clear choice;
- lexicographic rules: The attributes are ordered according to level of importance: the alternative chosen is the best for the most important attribute.
- utility rule: in the hypothesis that the attributes of the various alternatives are quantifiable, each alternative can be assigned a score, called utility, that represents the degree of user satisfaction. Naturally the same alternative usually has different utility values for different users.

The user choice criterion is represented by positing that the user chooses the alternative with the greatest utility value, compatible with his own economic and time availability. The formalization of the choice criterion is thus represented by the following optimization problem:

\[ U(c, t, d, r, g, \ldots) = \max \]

with the following meanings for the symbols:
- \( c \) = overall trip cost;
trip time;
discomfort during the trip;
income;
personal taste or preference;
and with the following constraints on income and time:

\[ \sum c_i \leq r \]
\[ \sum t_i \leq T \]

\( T \) being time available to the user.

A better schematization of the user choice process was proposed by Manski in 1977, with the introduction of the concept of casual utility. There exist, in fact, in the choice process numerous factors of randomness, not observable by the analyst and dependent on individual characteristics, including:

- attributes neglected in the model;
- unforeseeable variations in taste or mood;
- errors in measuring the values of some attributes.

In the more general form, the utility of alternative \( i \) for user \( n \) is thus expressed as the sum of an observable term, \( V_i(n) \), called systematic utility, and of a non-observable term, the random disturbance element \( \varepsilon(n) \):

\[ U_i(n) = V_i(n) + \varepsilon(n) \]

The probabilistic disaggregated models do not indicate with certainty which alternative the user will choose, but express the probability that the user will choose a certain alternative. **Systematic utility** is usually expressed as a linear combination of non-linear functions of \( k \) attributes of each alternative:

\[ V_i(n) = \sum a_k x_{ik} \]

Systematic utility \( V_i(n) \) is normally assumed constant for all users. In the case of an individual route choice model, since the object of study is the individual user, \( V_i(n) \) is constant in parity to the values assumed by the attributes of alternative \( i \) and in parity to the purpose of the trip \( h \), but varies from user to user. In fact, as shown by several investigations (see: Carrese, Fusco and Gori, 1991b), it is necessary to consider different utilities \( U_i(n) \) for different purposes \( h \).

According to the theory of casual utility the probability that an individual \( n \) will choose alternative \( i \) of the choice set \( C_n \) can be posited in the form:

\[ P_n(i) = \text{Prob}\{V_i + \varepsilon_i \geq \text{max} (V_j + \varepsilon_j), \forall j \in C_n, j \neq i \} \]

More generally, some factors responsible for the casuality of the utility of one alternative are correlated with the factors relative to the other alternatives. Expressing then the density function of joint probability of the casual disturbance terms of the various alternatives with the function \( f(E) \), where \( E=(\varepsilon_1, \varepsilon_2, \ldots, \varepsilon_n) \), the probability that the user \( n \) will choose, for example, alternative \( I \) can be written:

\[ P_n(1) = \int_{E_1} f(E) dE \]

where the higher extreme of integration is:

\[ E_1 = (+\infty, V_1 - V_2 + \varepsilon_1, \ldots, V_1 - V_N + \varepsilon_1) \]
Rather than solve the multiple integral, it is possible to express the problem of choice between multiple alternatives as a problem of binary choice between one alternative and all the others: thus, the probability that alternative $i$ will be chosen can be expressed with the condition that its utility is greater than the maximum utility of the remaining possible alternatives:

$$P_n(i) = \text{Prob}\{V_i + \epsilon_i \geq \max (V_j + \epsilon_j), \forall j \in C_n, j \neq i\}$$

To use the foregoing equation it is, therefore, necessary to solve the maximization problem:

$$\max (V_j + \epsilon_j), j \neq i, j \in C_n$$

which is usually difficult to solve.

The choice models usable at the operative level, such as Logit and Probit, have, therefore, been derived by positing different simplifying hypotheses per the distribution of joint probability $f(E)$ of the random disturbance terms.

The level of simplification of the model can be validly represented by the variance-covariance matrix, consisting of terms of variance and covariance, or moments of the II order, of the distribution of joint probability:

The most general case is represented by the multinomial Probit model, whose only hypothesis is the symmetry of the dispersion matrix.

The simplest expression of multinomial choice model is represented, rather, by the Logit model, in which the values of the principal diagonal of the dispersion matrix are all equal, while all the others are null: it can be hypothesized, that is, that the random disturbance terms of the various alternatives are distributed independently.

In an route choice problem the choice alternatives are represented by the various routes. Where the characteristics of the various links of the network are substantially similar, it is possible to hypothesize that the random terms of the various links are independent and represent the correlation between alternatives by means of links common to several routes.

3.1. THE LOGIT MODEL

The first expression of the Logit model relative to a binary choice problems was made in 1959 by R. Luce, who formulated the principle of the independence from irrelevant alternatives.

According to this principle, the relationship between the probability of choice of two alternatives is not influenced by the presence of a third alternative. If the two alternatives A and B have respectively the probability $P_A$ and $P_B$ of being chosen, a third new alternative will have a choice probability $P_C$, and the relationship $P_A/P_B$ will remain unchanged.

The model is based on the formulation of the following hypotheses:
1) the distribution of probability of the random disturbance term of each alternative is independent of the distribution of all the others;
2) the random disturbance terms of the various alternatives are all distributed identically;
3) the distribution of probability of the random disturbance terms is a Gumbel's function.

The hypothesis that the random disturbance terms are independently and identically distributed permits attaining a relatively simple form of the choice model but constitutes, in some cases, an excessive simplification of the problem.

The multinomial Logit model, in fact, can be correctly applied to the problem of route
choice in the case of a network in which the possible paths do not have links in common and do have similar characteristics.

On the contrary, in the case of choice between two road routes, \( I_1 \) and \( I_2 \), with very similar plano-altimetric characteristics, and a longer but faster highway route, \( I_3 \), the application of the logit would be incorrect (see fig.1).

![Figure 1](image_url)

**Fig. 1** Example of incorrect application of the Logit Model.

In this case it is, in fact, probable that a user, who between \( I_1 \) and \( I_3 \) prefers \( I_3 \), between \( I_2 \) and \( I_3 \) will continue to prefer \( I_3 \), since \( I_1 \) and \( I_2 \) have similar characteristics. That is, there exists a positive covariance between the random disturbance terms \( \varepsilon_1 \) and \( \varepsilon_2 \). In order to get around these limitations of the multinomial Logit model, the Nested Logit model was formulated, in which it is admitted that there exists a covariance between groups of alternatives.

### 3.2. **The Nested Logit Model**

The structure of the Nested Logit model is based on the principle of composite utility, applied for the first time to a Logit model among multiple alternatives by Daly and Zachary in 1976, and based on the sequential comparison between pairs of alternatives.

According to the structure of composite utility, the problem of choice among three alternatives \( A, B \) and \( C \) is resolved with a first comparison between \( A \) and \( B \), ignoring \( C \) and determining separately the probability of choice \( n_{A,B} \) of \( A \) with respect to \( B \) alone and the probability of choice \( n_{B/A} \) of \( B \) with respect to \( A \) alone.

At this point is defined an alternative consisting of \( A \) and \( B \), indicated by \( P \), and a new binary comparison is made between this and alternative \( C \). The overall probability of choosing \( C \) with respect to the composite alternative \( P \) is indicated by \( n_{C/P} \).

The overall probability of choosing alternatives \( A \) and \( B \) are then:

\[
\begin{align*}
    n_A &= n_{P/C} \times n_{A/B} \\
    n_B &= n_{P/C} \times n_{B/A} \\
    n_C &= n_{C/P}
\end{align*}
\]

The composite utility structure at the basis of the Nested Logit corresponds to a subdivision of the choice set of the user in subsets consisting of alternatives that the user perceives in a similar manner.

In the preceding section a problem of route choice has briefly been illustrated in which the correlation between two alternatives rendered inaccurate the schematization of the Logit
multinomial model, but that can be more correctly resolved with the Nested Logit.

In the case shown in Fig. 1, where there exists a positive covariance between two alternatives similar to each other but significantly different from the third, the choice problem can be resolved by including the two similar alternatives \( I_1 \) and \( I_2 \) in the same subset and the third, \( I_3 \), in a different subset.

The first choice process is made within the first subset between alternatives \( I_1 \) and \( I_2 \); in this case, in fact, the choice between \( I_1 \) and \( I_2 \) is not influenced by the third alternative \( I_3 \). Subsequently, \( I_1 \) and \( I_2 \) are replaced with equivalent composite alternatives and the probability of choice between the latter and \( I_3 \) is evaluated.

Another example, in which the application of the Nested Logit model to a route choice problem can be illustrated more clearly, is represented by the network shown in Fig. 2, in which two paths are connected to one another by a common link.

The first step of the method of resolution consists of a first choice within the subset constituted by the independent links \( a \) and \( b \), belonging to routes 1 and 2. The second step is the replacement of the links \( a \) and \( b \) with an link \( l \), composed of \( a \) and \( b \).

![Figure 2](image_url)

**Fig. 2** Representation of the procedure of replacement of the connected links with the Nested Logit model.

### 3.3. THE FULLY CORRELATED LOGIT MODEL

The fully correlated Logit model has recently been developed by Langdon by applying to the Logit multinomial the separated split structure which permits better representation of the correlation existing between the various alternatives in the problem of route choice.

The first step in the procedure of the separated split structure consists of a first choice between alternatives \( A \) and \( B \), after which the population is divided into two groups, those who choose \( A \) and those who choose \( B \), \( P_A \) and \( P_B \).

The second step is the binary choice process between alternatives \( A \) and \( C \) (for the first group) and the alternatives \( B \) and \( C \) (for the second group). In this second round, the previous choice is considered non-influential.

Langdon notes that this is the correct application of the principle of independence from irrelevant alternatives, in that for those individuals who between the two similar alternatives \( A \) and \( B \) have already chosen \( A \), in the subsequent choice between \( A \) and \( C \) the presence of \( B \) is irrelevant.

The overall probabilities of choice of the various alternatives assume then the following expression:

\[
\begin{align*}
 n_A &= n_{A/C} \cdot n_{A/B} \\
 n_B &= n_{B/C} \cdot n_{B/A} \\
 n_C &= n_{C/A} \cdot n_{A/B} + n_{C/B} \cdot n_{B/A}
\end{align*}
\]
where the superscript indicates a situation in which a first choice has already been made.

The procedure can be repeated in the case of four or five alternatives, but the combinatorial nature of the method of solution of the problem impedes practically the extension of the model to a case of choice between more than five alternatives.

3.4. THE PROBIT MODEL

In the Probit model it is assumed that the random disturbance terms that enter into the definition of the function of utility are the result of a broad series of unobservable and independent factors. Their distribution function tends, therefore, to be normal. This model was used for the first time in the field of toxicology, to evaluate the probability $P_i$ that an individual in a population of laboratory rats would survive the administration of a dose $V_i - V_j$ of poison.

In transport, Probit was first applied in 1967 to a binary model of modal split for the city of Chicago. Other applications are still limited to the case of binary choice, in that the hypothesis of normal distribution of the random disturbance terms makes this model difficult to use in the case of multiple choices.

The Probit model presents the more general form of the variance and covariance matrix of the random disturbance terms: the only hypothesis made is that this matrix is triangular; while the various elements can assume any value. Under this hypothesis, the random disturbance terms appear distributed according to a normal multivariate random variable. In the case of multiple alternatives the multinomial Probit model permits thoroughly specifying the correlation between the alternatives, but presents significant problems in practical applications, since it is not possible to resolve the expression of the probability of choice in closed form.

Thus have been proposed some approximate methods of estimating the probability of choice. The most widespread of these methods is Clark’s approximation, which, as in the Nested Logit model, employs a composite utility structure. The network is resolved through successive simplifications, obtained by replacing the real links with bogus links, whose utility is composed from the utility of the previous links. Hitherto the Probit model with Clark’s approximation has been employed only in research.

3.5. COMPARISON OF THE FEATURES OF THE DIFFERENT MODELS

Comparisons of the results obtained with different models of route choice have been made by Tzeng, Shieh and Shiau (1989) for public transport and by Langdon (1984) in a simulation study. Langdon conducted a study on a problem of choice between alternatives, comparing the results supplied by the various behavioural models.

In the case of six alternatives, the results obtained with a method of exact integration have been compared with the values supplied by the fully correlated Logit model and by the multinomial Probit model resolved with Clark’s method or with separated split procedure.

The best features were obtained with the Probit model with a separated split structure. The fully correlated Logit model continues to work fairly well for both low and high values of the differences in utility. The Probit model with Clark’s approximation supplies values sufficiently near those of the simulation when the deviations standard of utility do not differ much among the various alternatives. On the contrary, occasional large errors occur when the utility variances of different alternatives are very different. Another inconvenience of Clark’s method is the tendency to overestimate the probability of choice of a lower value. It has been confirmed, finally, that the simple multinomial Logit is not suitable for route choice problems when there exists a notable utility distribution variance.
4. ROUTE CHOICE MODELS

Road users' route choice process has been studied by different authors, as much with theoretical models (Hamerslag, 1981) as with empirical models (Heathington, 1971; Ueberschaer, 1971; Duffel and Kalombaris, 1988).

In numerous cases empirical models have been applied to route choice problems to identify the variables that, in general, enter into users' choice processes and therefore to determine the percentage of users to assign to each route. The technique with which the phenomenon is studied is not in general of the regressive type: a certain number of variables is identified able to describe the phenomenon, the data assumed by these variables are gathered observing a real case, a formal expression that describes the link between the variables is hypothesized, the effects of the various variables in play are quantified with regressive techniques.

In the case of an individual on-board route guidance system, the itinerary-choice behaviour of the individual user can equally be studied with probabilistic models. In this case the variability is due, on the one hand, to the irrational component of the use, and on the other to the inadequacy of the system in describing its behaviour. The data base is constituted by a series of observations on choices made by the user during his trips. The route guidance system must be able to continuously verify in time: the expert systems, able to update themselves, seem able to perform this task. This will be the object of research in coming years.

The studies cited above have shown a variation in the perception of time on the part of the users as external conditions vary: for example, from an analysis made in the 1970s based on Chicago motorists (Heathington, 1971), it emerged that the users are more sensitive to anomalous situations that bring unforeseen delays than to situations of habitual congestion.

The link that, through various factors, ties subjection perception of time to objection time has been assessed by Leiser and Stern (1988) on a data base constructed by means of a simulation model of urban driving. The variables taken into consideration for the construction of subjective time are the same as those in the determination of objective time: distance, speed, presence of obstacles (traffic lights and turns).

The effect of the obstacles can be understood by considering that the perception of subjective time is such that the "mental clock" runs faster than the real one if the user is asked to perform a difficult task, that is, if a high degree of attention is requested of him. Thus, while the presence of traffic lights produce an increment of subjective time, the presence of turns should reduce it. On the other hand, the presence of turns normally brings waits that, on the contrary, negatively influence the perception of time. Speed, on the one hand, increases the degree of attention, thus reducing the perception of time, but on the other hand it involves a greater frequency of events and thus an overestimation of the time. The effects, direct and indirect, of independent variables on the subjective perception of time have been evaluated using regression analysis.

In the final analysis, objective time and density of obstacles on the route are the two variables that greatly influence, and almost in equal measure, the subjective perception of time by the road user. It should, finally, be stressed that the model has been utilized with data generated in simulation and that, therefore, further investigation is necessary to determine whether the results obtained correspond to reality.

The model for the valuation of subjective time could be utilized in a route choice problem, by replacing objective time with subjective time. In this way the schema of the road network on which the user decides the route does not represent the network on which the user moves, but is its representation distorted by the subjective perception of travel time.
5. TRIP-CHAINS

Among different behavioural models of route choice, particularly important are those that keep account of interdependence between trips of a chain: such trips neither originating nor ending in the dwelling place, make up from 15 to 20% of the mobility within Italy's major cities.

Usually these trips are non-regular, non-recurring and often non-programmed and thus they will be carried out more efficiently by private transportation.

From a recent survey amongst residents in the city of Rome, it has been estimated that the percentage of direct journeys (as, for instance, a home-to-work or home-to-school journey) has reduced from 38.5% in 1964 to 28.5% in 1988, with a corresponding 10% increase of journeys carried out to access different types of Administrations, for recreational purposes, etc...

This result can be interpreted as the fact that private transport users are prone to joining trips that may be required to fulfill certain needs, in a single trip-chain in which the destination of a trip is regarded as the origin of the following one.

Such a behaviour is due to subjective estimation of travel time by the user who, because of increasing (vehicular) traffic or lack of time, prefers to include several specific trips (movements) in a one trip chain. (single chain-linked route)

5.1. REPRESENTATION MODELS FOR TRIP-CHAINS

The models used for the representation of the phenomenon are derived from the previously illustrated utility disaggregated models; the main feature characterizing them is the interdependence of the choices at the various levels.

In recent technical literature (Horowitz 1980, Adler and Ben Akiva 1979), models of deterministic types have been considered, but although they furnished results in agreement with actual data, they have been abandoned because of intrinsic difficulties in the representation of the aleatory structure of trips.

The basic assumption in these models is that the analysis of the choice of destination is carried out each time separately and independently, so that any relationship existing among choices made by a user within a trip-chain, is neglected.

Random utility models have thus been proposed. These introduce a parameter to represent the dependence of the choices in order to obtain a more general view on the concatenation of the destinations. Please refer to the first part of this work for a specific description of these models.

As was previously stated, trips can be carried out for many purposes as, for instance, shopping, recreation, etc.. Home-to-work trips are not included among these, but there can be some exceptions.

Several studies have pointed out that the structure of such trips depends very much on the activities carried out during the stops. It has been noticed that, in certain cases, the percentage of journeys with several intermediate stops may be as high as 30%. For the representation of this type of journey, it is necessary to disaggregate the single trips (of the journey) in accordance with the constraints related with the type of activity.

We thus turn our attention to the purpose of the journey and we define a sojourn as a visit to a place different from the dwelling place. During a sojourn one or more activities can be carried out. The trip from the dwelling place to a sojourn or between two sojourns, will be referred to as trip link. A sequence of consecutive trips, originating and ending in the dwelling place, will be referred to as trip tour.

The model for destination choice in put together using the prospective utility of a destination area, as a measure of its attraction: in a trip-chain the next destination depends
upon previous choices.

We aim to show that the behaviour of choice destination can be adequately represented in correlation with exogenous factors only when considering the trip-chain in an analytical way.

Thus, a relationship is introduced to assign every area with a series of attributes, in order to classify them in accordance with the criteria of the prospective utility of visiting that area.

The probable utility of a zone understood as a sum of opportunity is defined as follows:

\[ U_j = V_j + \sum_{k \in E} q_{jk} \left( U_k - d_{jk} \right) \]

where:
- \( U_j \) is the probable utility of zone \( j \);
- \( V_j \) is the measurement of utility determined only by the attributes of zone \( j \);
- \( q_{jk} \) is the subjective probability that the user will visit place \( k \) after visiting \( j \);
- \( d_{jk} \) is a measurement of the distance between \( j \) and \( k \);
- \( E \) is the series of zones;
- \( \theta \) represents the disutility linked to the trip by a unitary distance.

A disaggregation for the purpose of a trip may be conducted by defining the probable utility of a zone according to purpose, as

\[ U_{aj} = V_{aj} + \sum_{k \in E} q_{ak} \left( U_k - d_{ak} \right) \]

where \( a \) indicates the purpose of the trip and \( C \) is the series of categories of trip purposes.

5.2. TRIP-CHAINS IN DESTINATION CHOICE

In the study of route guidance systems, the issue of trip-chains can be viewed from several points. In fact, the user may find himself in the need to question the system about the following situations:

a) from origin \( O \) to destination \( D \), via \( C \). This case can also be treated as the case of two different journeys; this approach may be necessary if the stop in \( C \) lasts long enough to permit a considerable change of flow conditions;

b) from origin \( O \) to destination \( D \), with an intermediate stop so to as satisfy purpose 1. This is the quite frequent case of brief stops for shopping or quick errands as, for instance, newspaper, chemist, petrol, in a regular journey of the home-to work type. The temporary stop is not restrained to any particular place, since, during the journey, there are several opportunities to satisfy the aforementioned needs;

c) from origin \( O \) to destination \( D \) making intermediate stops to satisfy purposes 1,2,...,n, with or without priority claims. This is the most complex case and it includes the typical trip tour for shopping or errands, ending with the return home. Moreover, among the purposes under consideration , there can be strong constraints or priorities such as the search for a petrol pump just before one runs out of it, or the purchase of a gift before the shop closes.

The problem, in general, can be set in the following way.

**ORIGIN** : - known;

**DESTINATIONS** : - fixed (specified in locations);
- variable (specified in purposes);

**OBJECTIVE** : - reach the selected destination optimizing the path according to the personal user criterion;

**CONSTRAINTS** : - maximum arrival time for one or more destinations;
The problem of the optimum path choice can then be faced according to the following general procedure:

- a graph is constructed of the destinations in which destinations that satisfy the same purpose are not linked with one another (Fig.3). The graph thus constructed permits connecting each individual destination to the heterogeneous destinations, that is belonging to different-purpose classes, and to origin O and destination D;
- The path tree is then constructed, which permits identifying all the possible paths that depart from O and can reach D after having made a stop at G and S (Fig.4); naturally is then verified the compatibility of each individual itinerary with the possibility of being effectively travelled by the means of transport considered by the user (traffic disciplines, areas with limited traffic, etc...);
- Then is identified a series of possible trips that can be alternatively usable according to the choice criterion utilized;
- identification of the best path (one-to-many) keeping in mind objectives and constraints (Fig.5). In the example illustrated is considered for simplicità the criterion of choice of the minimum distances but any other criterion can be adopted after appropriate evaluation of the arcs according to the parameters to utilize (travel time, generalized cost, etc...)

In this case the determination of the best path is an easily solvable problem but the illustrated schema here can be applied even in more complex cases.

In particular the application of this procedure to a route guidance system permits the use on board the vehicle of the implementation of multicriteria techniques in the choice of a route, which has been discussed, as well as needed information elaborated by the central system, on the territorial distribution of services (parking, public offices, etc...) and commercial activities with the updating of schedules, availability, and other characteristics.

Fig.3 Networks of links between destinations
5.3. **Multiple Determination of the Route**

It is usually remarked that the indications provided by the route guidance system, are too inflexible and that, on the other hand, the behaviour of drivers is often too flexible.

The previous study of behavioural models has pointed out the reasons of the aleatory component in probability models. In the case of trip-chains, there are even more elements of uncertainty in choosing the route. That is because of utmost flexibility of the needs and manifold possibilities of satisfying them. Furthermore, as already stated, the situation in which the user is not satisfied with the "best" route provided by the system, can be avoided if he is allowed to choose among different alternative solutions. We are thus led to take into consideration any possible solution, not only the optimum solution to the problem previously defined by the multi-criteria function.
6. CONCLUSIONS

In this paper some considerations about route choice criteria has been performed. Since human behaviour varies so much, the application of the classic maximum utility multi-objective model requires a sufficiently flexible applicative methodology in order that, at the beginning of the journey, the route guidance system may update itself on the objectives and on the criteria chosen by the user, and in order that, at the end of the journey, it may verify the degree of approximation to the wishes of the user.

Thus, the use of a qualitative model was proposed to interpret the choice behaviour by means of a survey at the moment of departure. The following procedure was used:
- construction of the multi-criteria utility function of the user of the system;
- determination of the weights and gauging of the function;
- computing of the minimum path in accordance with the user custom-made function;
- forecasting the introduction of the expert system into such a methodology.

Some other issues remain open, regarding how the route guidance system reacts to traffic conditions. The following development lines result:

1) the route guidance system must be capable of interpreting the dynamic evolution of the network;
2) in case of widespread use of the system, the system must be capable of assigning the correct amount of traffic flow onto different routes.

The first issue was examined in a previous phase of the research and, as shown by large scale experiments such as LISB, the results are that the system is capable of collecting data on traffic conditions and of real-time processing, even in large networks.

The use of an on-board processing system, along with the central control system, permits to keep account of specific local situations that may affect the user.

Further investigations are, all the same, required to understand the phenomenon of the spread of anomaly conditions in a congested network.

For the second issue, neglected even in the most advanced route guidance system so far tested, no correct theoretical approach has been investigated; in fact, to reduce the time needed to update the system and therefore to speed up the progressive agreement of the system to the dynamic evolution of traffic conditions, technological progress has been relied upon. Furthermore since each user is assigned his route in accordance with his own choice criterion, it is possible to distribute traffic flows on more routes.

These two issues will be further investigated in the next phases of the research.

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Development of Checking System of Guiding Road Signs Using Digital Road Map Data Base

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Abstract of speech:
In recent Japan, according to the popularization of automobile transportaion, road signs are expected to get more correct and more easy-to-understand. To fulfill the needs we need some check systems of road signs with which we can check road signs rapidly and easily. And the checks should be on the basis of the behaviour of drivers. We developed a system to do the check using digital road map data base and guiding road sign data filed in computer files.

The system checks whether drivers can reach their destinations by simulating actual behavior of drivers who drive following their destination names on guiding road signs. If there is a case where the guiding road signs fail to guide the driver, the state of the failures are indicated. Other checks on guiding road signs have got easier to do because we made the list of them in computer files.

We have applied the system to the 1580 guiding road signs (4945 destinations) on the roads upper than prefectural (except municipal) in the north of Chiba prefecture which lies in the suburbs of Tokyo. The result is that drivers are correctly guided to their destinations in 62% of all the cases. This rather low percentage of successful cases can be attributed to the fact that the system of guiding road signs in the area is not complete.

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Development of Checking System of Guiding Road Signs Using Digital Road Map Data Base

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1. INTRODUCTION

Driving is no longer a specialised skill but has become a popular activity engaged in by all and sundry in Japan, with an increasing number of elderly drivers and of "Sunday drivers." This has given rise to a demand for making roads easier to drive on and in particular for making informatory signs easier to understand.

The practice with informatory signs in Japan has been to select important place names and to display them on the signs. While this means that names of places in the immediate vicinity and of distant but important places are displayed on each sign, there are still cases where the discontinuity in the information provided, that is, the disappearance of place names displayed once on signs further on, and the lack of signs at certain intersections result in the drivers failing to reach their destinations. At the same time, although in devising the installation plans for informatory signs efforts are made to ensure coordination between the national government and prefectural governments, as well as between prefectural governments and between municipalities within prefectures, this is done only on paper, without comprehensive checks on computers, with the result that the continuity of the information is not always guaranteed. There is a need therefore to carry out checks on signs already in place as well as on installation plans for new signs, as to 1) whether an ordinary road user will be able to reach his or her destination without becoming lost on the way relying simply on the place names displayed, and 2) whether the place names are displayed in a manner that is easy for the ordinary road user to understand. Carrying out such checks on paper would require vast amounts of time and labour and much work would be required again when new roads are constructed or when existing roads are renovated. The Ministry of Construction has developed a computerised system for efficient implementation of such checks through a combination of the digital road map data base and a newly-created data base for informatory signs.

2. INFORMATORY SIGNS IN JAPAN AT PRESENT

2.1 Principles for Provision of Information

While, in general, informatory signs on roads might provide information in the form of place names or route numbers, use of route numbers is made difficult in Japan by the complexity of the road network. As a result, place names are used in the main in Japan, with the corresponding route numbers displayed as subsidiary information. The names of principal places that are to be displayed on signs are selected for each of the ten regions in Japan, and these are classified into three ranks according to their significance for display on signs on roads of different ranks as shown in the table below.
Table 1. Ranks of place names

<table>
<thead>
<tr>
<th>Place Name</th>
<th>Rank</th>
<th>Significance Rank 1</th>
<th>Significance Rank 2</th>
<th>Significance Rank 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major Arterial Roads</td>
<td>☀</td>
<td>☀</td>
<td>☀</td>
<td>☀</td>
</tr>
<tr>
<td>Arterial Roads</td>
<td>☀</td>
<td>☀</td>
<td>☀</td>
<td>☀</td>
</tr>
<tr>
<td>Collector Roads</td>
<td>☀</td>
<td>☀</td>
<td>☀</td>
<td>☀</td>
</tr>
</tbody>
</table>

○ Place names mainly used  
□ Place names which may be used on signs with plural number of place names

Besides the names of places in the immediate vicinity along the road, names of a plural number of important places further on are indicated on each informatory sign in principle to ensure continuity of the information provided. Names also of places off the given route may be displayed if these are of particular importance.

Figure 1. Typical Informatory Signs

2.2 State of and Checking System for Informatory Signs

While informatory signs in Japan are installed by the administrators of the relevant roads (national, prefectural and municipal governments), “regional committees on traffic signs” have been created in each district and the installation plans are drawn up ensuring coordination between the national, prefectural and municipal governments. The present state of the informatory signs and the installation plans for them are recorded on registers by each of the road administrators. The progress of the work on informatory signs is expressed in terms of the number of signs installed over the number of signs to be installed under the installation plans, with no indication of the level of the guidance provided by the signs.

3. COMPOSITION OF CHECKING SYSTEM

3.1 Digital Road Map Data Base

The data base was developed for motorcar navigation and progress of road administration with the following considerations.

1) The data base should allow application of map matching (technique for improving the accuracy of the judgment on vehicle positions through comparison of the record of motion and the map installed on the vehicles).
2) The data should have a structure that allows reading of road structures (carriageway width, number of traffic lanes etc.) and restrictions (traffic classification etc.) which are of direct relevance to the drivers.

3) The data should include background information (rivers, railways, major facilities etc.) in addition to the data on the road network to facilitate reading of the display.

The road data are recorded in the form of links and nodes at the origins and termini of the links. The links are stored as link data together with the information on the complementary points that indicate the shapes of the links. The nodal information consists of the information on the links with which the nodes connect and that on the location and coordinates of the nodes (based on the Numerical Land Data mentioned below) and are stored as the node data. The information on the background, such as rivers and railways, is stored as background data.
Topographical maps on the scales of 1:25,000 and 1:50,000 published by the Geographical Survey Institute, which cover the whole of Japan, have been used as the basic materials for the preparation of the data. In addition, the information collected from the road administrators and that obtained from the road traffic censuses conducted throughout Japan has been used, for example, for the detailed drawings for complex intersections, road structures and traffic restrictions. The positional expression on the digital road maps follows that of the Numerical Land Data, with three-level mesh divisions and coordinate expression of the smallest meshes. (The Numerical Land Data were prepared by The Geographical Survey Institute by computerising the topographical maps prepared from general use.)

The preparation of these digital road maps began in 1986 and they now cover the whole of Japan. These maps are under the management today of the Japan Digital Road Map Association and are being used in various navigation programmes.
Figure 4. Concept of Digital Road Map Meshes
3.2 Composition of Checking System for Informatory Signs

1) Data Composition
A connection is made between the contents of the informatory signs that are in place and the location of the places indicated on the signs using the node and link information on the digital road maps.

(Data Composition)
a) Destination Place Name Data
The meshes in which the places whose names are indicated on the signs within the check area are to be found and the nodes found in that mesh are recorded.

<table>
<thead>
<tr>
<th>Secondary mesh containing destination</th>
<th>Name of destination</th>
<th>Node number for destination</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 S39396</td>
<td>8</td>
<td>17</td>
</tr>
<tr>
<td>41</td>
<td>1361240 1361262</td>
<td>1351244 1361355 1361269 1361353 1361354 1361092 1361172</td>
</tr>
<tr>
<td>42</td>
<td>1361201 1361356</td>
<td>1361211 1361357 1361276 1361358 1361359</td>
</tr>
</tbody>
</table>

Figure 5. Destination Place Name Data

b) Sign Place Name Data
The node number of the location at which the signs are found and the contents of the signs are recorded for all informatory signs within the check area.

<table>
<thead>
<tr>
<th>Prefecture Code</th>
<th>Sign Number</th>
<th>Route Number</th>
<th>Sign Type</th>
<th>Grade Separation</th>
<th>Secondary Mesh Number</th>
<th>Number of Edges or Nodes away from (Tokyo)</th>
<th>Direction 1</th>
<th>Direction 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>1 3 14 2</td>
<td>0</td>
<td>534030</td>
<td>421</td>
<td>6 + A + A + 2</td>
<td>1 + 3 + 14 + 2 + 東京 飛橋</td>
<td>#</td>
<td></td>
</tr>
</tbody>
</table>

Figure 6. Sign Place Name Data

c) Road Network Data for Check Area
Breakdown from the digital road maps

The overall composition of the system is shown below.

Figure 7. Composition of the System
2) Check Programme
The movement of the check programme simulates that of a driver following the informatory signs and checks whether a driver seeing a place name on a given sign can reach his or her destination by following the informatory signs from there. The following basic rules are used in making the judgements.

a) If the place name in question is indicated at an intersection, the driver will follow the sign.

b) If there is no informatory sign, or if there is a sign but the place name in question is not indicated at an intersection, the driver will either follow the same route or travel straight on, but if this occurs three or more times, the destination is considered unreachable.

The algorithm for the check programme is given in Figure 8. Since the data base does not yet contain data on the signs at the municipal level, the checking process is discontinued when the imaginary driver enters a municipal road.

![Figure 8 Algorithm for Informatory Sign Check Programme](image)
4. CHECK RESULTS

4.1 Example of Continuity Check

The check on the continuity of the signs is implemented according to the following procedure.

1) The sign data attached to the network are extracted one by one.
   Travelling up (towards Tokyo) on Ordinary Municipal Road Route 244 (Togawa Port Route), the
   imaginary driver sees Sign No. 10.

2) The destinations given in the sign data are picked out one by one.
   The destination “Inubozaki” is picked out.

3) If the name of the destination picked out in 2) is found in the destination data, the sign is made the
   starting point and the imaginary driver travels along the links following the directions given in the
   signs.
   The driver travels to Node 84, as the direction given in the sign for Inubozaki is to travel straight on.

4) When there is no sign or the destination name is not given in the sign, the imaginary driver will
   either follow the same route in the direction he or she is travelling (1st condition) or failing that travel
   straight on (2nd condition).
   Since there is no sign at Node 84, the driver follows the 1st condition and travels along the same
   route to Node 83.

5) If there is an intersection and the destination name is included in the sign, the imaginary driver will
   proceed in the direction close to the angle indicated in the sign flag.
   The driver proceeds to Node 85, as the direction given for Inubozaki at Node 83 is straight on.

6) If two directions are given for the same destination at an intersection, the imaginary driver will fol-
   low the direction given first in the sign data.
   Two directions, straight on and right turn, are indicated for Inubozaki at Node 85. Since the data giv-
   ing the direction to travel straight on is given first in the sign data for Sign No. 8, the driver will
   travel straight on.

   Since there is no sign until Node 28, the driver will travel straight on in accordance with the condition that
   the imaginary driver should travel straight on when there are no signs, and reach Inubozaki, which is the des-
   tination.

   The continuity check is completed when the above procedure has been repeated for all signs in the area in
   question.
Figure 9. Example of Continuity Check
4.2 Check Results

A continuity check was carried out on a total of 4,945 destinations indicated on 1,580 informatory signs situated on the national and prefectural (but not municipal) roads in the northern part of Chiba Prefecture. The results are discussed below.

1) Check on Success Rate in Reaching Destination
   
   Table 2 shows the percentages of cases where the destinations given on the signs were reached successfully by following the subsequent signs (arrival rate) in accordance with the algorithm discussed in 3.2. The arrival rate was around 60%, excluding from the calculation the cases where the imaginary driver found him or herself on municipal roads which were outside the scope of the check.

   Table 2. Check Results (1)

<table>
<thead>
<tr>
<th>Number of Place Names</th>
<th>Ratio to 4</th>
<th>Ratio to (4-3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Successful Guidance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-1 Arrival at destination</td>
<td>2,203</td>
<td>44.6</td>
</tr>
<tr>
<td>1-2 Guidance to boundary of area for destination outside area</td>
<td>244</td>
<td>4.9</td>
</tr>
<tr>
<td>2. Failure</td>
<td>1,490</td>
<td>30.1</td>
</tr>
<tr>
<td>2-1 Passed 3 signs without display for destination</td>
<td>581</td>
<td>11.7</td>
</tr>
<tr>
<td>2-2 Stopped at T-shaped intersection without sign</td>
<td>645</td>
<td>13.0</td>
</tr>
<tr>
<td>2-3 Dead-end in network</td>
<td>167</td>
<td>3.4</td>
</tr>
<tr>
<td>2-4 Others</td>
<td>97</td>
<td>2.0</td>
</tr>
<tr>
<td>3. Entered Municipal Road (outside scope of check)</td>
<td>1,008</td>
<td>20.4</td>
</tr>
<tr>
<td>4. Total</td>
<td>4,945</td>
<td>100.0</td>
</tr>
</tbody>
</table>
2) Results of Continuity Check on Destination Place Names
In the check for the arrival rate in 1), even if there is only one point with an unsatisfactory information sign the results for all the signs up to that point are given as failures. In other words, the arrival rate does not show the proportion of signs that provide satisfactory conditions. A check was carried out, therefore, on whether the place names given in the signs are given correctly in relation to the conditions before and after those signs (continuity) in order to calculate the proportion of signs providing satisfactory directions. The results are given in Table 3. The continuity rate was found to be around 80%, excluding the cases where the imaginary driver found him or herself on municipal roads. From this, even a partial improvement on the contents of the signs may be expected to result in a significant improvement also in the arrival rate.

<table>
<thead>
<tr>
<th>Table 3. Check Results (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Number of Place Names</td>
</tr>
<tr>
<td>1. Successful Guidance</td>
</tr>
<tr>
<td>1-1 Arrival at destination</td>
</tr>
<tr>
<td>1-2 Guidance to boundary of area</td>
</tr>
<tr>
<td>2. Failure</td>
</tr>
<tr>
<td>2-1 Passed 3 signs without display for destination</td>
</tr>
<tr>
<td>2-2 Stopped at T-shaped intersection without sign</td>
</tr>
<tr>
<td>2-3 Dead-end in network</td>
</tr>
<tr>
<td>2-4 Others</td>
</tr>
<tr>
<td>3. Entered Municipal Road (outside scope of check)</td>
</tr>
<tr>
<td>4. Total</td>
</tr>
</tbody>
</table>
5. FUTURE TASKS AND USE OF CHECKING SYSTEM FOR INFORMATORY SIGNS

5.1 The following improvements might be made in the system.

1) The criterion used for the continuity of the signs at present is that the continuity is considered as broken when there are 3 intersections in a row where the name of the destination is not given. There is a need firstly to consider the appropriateness of this number of intersections, and secondly to verify that the criteria are in line with the senses of an average driver, with considerations on whether there is a need to set upper limits for the number of signs seen during travel to the destination and for the travel distance.

2) The system can be applied, besides to checks on the existing signs, to investigations on which places the information should be provided for on a given route. In doing so, the system might be combined with the traffic volume data for investigations on provision of destination signs that are in line with the actual state of the principal traffic flow.

5.2 Advantages of System and Future Application to Practical Uses

While the system has as yet only seen test application in the northern part of Chiba Prefecture, it is intended that it should be applied to the day to day work of road sign management in other areas. Furthermore, while checks were carried out only on the signs already in place in the investigations reported above, continuity checks will be carried out with this system in future also on the installation plans for new road signs.

The application of this system is expected to result in the following practical advantages in addition to the ability to carry out continuity checks on road signs.

1) Integrated Control of Sign Data
   The creation of a data base for informatory signs will allow speedy response to enquiries and complaints concerning them, as well as being used in devising renewal plans for the signs and as management data.

2) Facility of Coordination between Road Administrators
   The system will facilitate investigations on the continuity and appropriate choice of destinations across boundaries between jurisdictions of road administrators (e.g. prefectural boundaries). In particular, the system will facilitate the solution of problems, such as the likelihood of being lost on roads of lower rank where the signs given on higher-ranking roads are not followed up.

3) Calculation of Changes in Arrival Rate with Progress of Sign Installation
   The changes in the arrival rate with the progress of the work of installing new signs can be calculated by inputting the installation plans into the system, allowing the progress of the work to be expressed in terms of the arrival rate instead simply of the number of signs installed.

4) Selection of Place Names for Signs on New Roads
   The system can be used as a supporting system for the work of selecting the place names to be displayed on the informatory signs when new routes are put into services.
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Car Characteristics and Safety

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Abstract

This paper aims at analysing accident rate and fatality rate according to car characteristics such as mass and horsepower, taking into account accident and exposure data. Accident rate is defined as the number of accident per kilometres travelled. Fatality rate is the ratio of fatalities per vehicles involved in accident: it is differentiated for the victims inside vehicles (protection) and those outside (aggressiveness).

The results show that light vehicles with high performances have a higher risk to be involved in accident per kilometres travelled. Considering internal and external fatality rate, it appears that the heavier vehicles provide the best internal protection and are the most dangerous for other road users. In terms of global fatality rate (both internal and external), the lightest vehicles are better, except for the particular category of light vehicles with high horsepower. Drivers’ age and accident location, inside or outside urban area, are also taken into account, insofar as it influences risk and fatality rate, and increases differences between various European countries.
CAR CHARACTERISTICS AND SAFETY

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1. INTRODUCTION

Drivers have at their disposal more high-powered cars, even though speed is often presented as one of the main causes of accidents and of their seriousness. This phenomenon is not new and studies have been carried out in France and abroad to measure its impact. The analyses revealed in the available literature agree in general and show that there is a greater risk for the highest performance vehicles, taking into account the use made of them by their drivers (Berlioz et al, 1973), (Fontaine, 1991).

The weight of vehicles is also an important criterion when evaluating the impact of safety and, according to the type of approach chosen, the conclusions can be different. Thus, in the United States, opposite views are expressed on the effect of severer restrictions on fuel consumption (standards for Corporate Average Fuel Economy), which can bring with them a reduction in the size and weight of vehicles. Some show that the risk of being killed is reduced when the weight of the vehicle increases (Evans, 1991) and forecast an increase in the number of victims following the introduction of such restrictive measures. Others, emphasise that the relationship between the weight of the vehicle and the risk of being killed is not so simple (Chelimsky, 1991) and that the highest number of victims is not to be observed in the group containing the smallest vehicles but in that of medium weights, which leaves open to question a possible effect of vehicle performance.

E. Chelimsky estimates that the increase in the number of small vehicles could lead to a slight reduction in the total fatality rate in two-car accidents.

Our objective here is to resume this type of analysis on the effect of vehicle performance and weight on safety, using recent French data. This effect will be measured on the one hand through the risk to be involved in accidents per kilometre covered and, on the other hand, through the seriousness, by making a distinction between internal and external seriousness.

2. METHODOLOGY

2.1 The indicators used

Two types of indicators will be analyzed:
- the risk of involvement in accidents for the same distance covered. This rate is estimated by the ratio of the distribution of the different types of vehicles involved in accidents to their distribution in all traffic. We will calculate a relative risk by taking the risk to the whole of the population to be equal to 1.

- the levels of seriousness per accident by distinguishing between internal (protection) and external (aggressiveness) seriousness. The protection offered to the occupants of a category of cars is estimated by the rate of death in vehicles of that class in comparison with the number of vehicles of that class involved in accidents with personal injuries. Aggression is measured by the external death rate.
that is pedestrians and other users in accidents with a vehicle in the class under consideration. So as to avoid an effect of vehicle occupancy rate variation, we have taken into account only drivers and pedestrians. In fact, occupancy rate varies not only according to the size of vehicles but also according to the age of the driver. Thus, this rate is nearly 1.9 for vehicles driven by those aged 18 to 21 and then falls to 1.6 for drivers over 35. Here one finds one of the components of a classic type of accident: young drivers with loss of control, at night, on leisure trips with several passengers on board (Fontaine et al, 1992).

2.2 The data used

The measure of exposure, considered here, corresponds to the distance covered. The data used come from a sample survey aimed at finding out car characteristics from questionnaires sent out by post each year (Hivert et al, 1992). The data used here are for 1990. The distances covered by cars are taken from the annual kilometres driven, as declared by the drivers. The usable sample is 5,183 vehicles for which the specific model was given.

Accident data are from the Police and Gendarmerie using their statistical forms and the police reports intended for legal action. These two types of document are drawn up systematically for each accident involving personal injury.

The statistical forms are collected in a national computerised file which provides a large number of items of general information on all accidents involving personal injury.

The police reports describe the facts in detail and mention the declarations of those involved. These reports contain location map and occasionally photographs. They give an overall picture of the accident without, however, being as complete as the detailed accident studies files. With the aim of having an intermediate database sited between the national statistical files and the information supplied by specific surveys, a police report file representative of the accidents with a survey rate of 1/50th has been maintained permanently within INRETS since 1987 (Fontaine et al, 1992). More than 3,000 police reports are, in this way, collected each year and are subjected to specific analysis, more detailed than in the statistical form. The objective is to permit, on the one hand an evaluation of the facts relying on criteria contained in the statements and, on the other, a re-reading of the documents for a more in-depth analysis of certain themes.

We have used the data from accidents which occurred in 1990. In the exhaustive form file, the specific models of about 85,000 cars are well documented. The 1990 police report file comprises 2,779 cars whose make, type and specific model are usable.

2.3 The category of vehicles used in the analysis

Only passenger cars are taken into account. The car performance will be analyzed using power per tonne. In fact, a very high-powered but heavy vehicle does not present the same technical characteristics as a vehicle of the same power but much lighter. The interaction of weight and power per tonne will be taken into account.

To map out the limits of the relevant classes, we have taken into account the distribution of numbers and characteristics specific to each class through a multi-criteria analysis. To do this, we have relied on a statistical criterion called "value test" and expressed in the number of standard deviations (Morineau, 1991). This is
the equivalent of comparing each class of vehicle in relation to the whole for each of the variables by measuring the distance between the percentage of a characteristic in the class and its percentage in the population, taking into account the numbers. Criteria have been considered as discriminant in the category when the value test is higher than 3. Each variable is examined separately, the interactions are not taken into account. The criteria retained in the analysis of the classes of vehicles concern:

- the driver: age, sex, profession, date of licence, civil status, reason for journey, residence, manoeuvre, responsibility, wearing of seat belt, alcohol level,

- the vehicle: age, number of passengers, ownership, type of fuel,

- the environment: type of road, built-up area, intersection, layout, width of road, weather conditions, state of surface, light, type of day, month,

- the type of accident: number of vehicles, accident involving a pedestrian, a two-wheeler or a heavy goods vehicle, type of collision, original manoeuvre, seriousness.

The data from the police reports were analyzed here, so as to have enough criteria to use. The analysis, carried out on 10 weight groups, shows that the different groups are firstly characterised by the fuel used (diesels are over-represented among the heaviest vehicles), and by the age of the vehicles. Then come criteria linked to the age and sex of the drivers. One can observe a certain continuity which corresponds to the use of the motor fleet: women and young people use light vehicles, while vehicles over 1 tonne are more frequently driven by men of 36 to 64 years. None of the criteria linked to the type of accident appears discriminant in weight beyond the threshold of 3 for the value test.

Taking number distribution and specific driver characteristics into account, 3 classes of weight seem worthy of note:

- under 800 kg
- from 800 kg to under 1000 kg
- 1000 kg and over

Since we hope to introduce the interaction of weight and power per tonne, we must also define a threshold for this criterion. An analysis of the same type as the preceding one, on 7 classes of power per tonne, describes this parameter using the fuel (diesels are under-represented below 70hp/t), the age of the vehicle (high powered vehicles are more recent), the driver’s sex (women drive low performance cars), the socio-professional class which is a reflexion of income and the possibility of buying more expensive vehicles and the driver age (young people are over represented in accidents involving vehicles of over 110 hp/t). The type of accident is also a discriminant criterion of power per tonne and one can note an over-representation of losses of control for vehicles of over 110 hp/t. In fact one vehicle out of 3 in this category is involved in a single-vehicle accident after a loss of control while, in the whole of our sample, it is represented only by one vehicle out of 5. This category of vehicle is also characterised, but to a lesser extent, (value test falling between 2 and 3) by drivers presumed to be responsible for the accident as well as by a higher level of "non-belted" drivers.

It seems therefore that the threshold of 110 hp/t is relevant to our analysis. We will keep 5 classes, as numbers of vehicles of under 800 kg and of over 100 hp/t are too low. Table 1 reproduces the main characteristics of these classes.
<table>
<thead>
<tr>
<th>class of vehicles</th>
<th>percentage in police reports</th>
<th>over-represented characteristics in police reports</th>
</tr>
</thead>
<tbody>
<tr>
<td>under 800 kg</td>
<td>32%</td>
<td>petrol, women, single, 18 to 21, student</td>
</tr>
<tr>
<td></td>
<td></td>
<td>borrowed vehicle, employee, local driver</td>
</tr>
<tr>
<td></td>
<td></td>
<td>vehicle older than 10 years, driver alone</td>
</tr>
<tr>
<td></td>
<td></td>
<td>slight injuries, town of 5 to 50,000 inh.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>commuter</td>
</tr>
<tr>
<td>from 800 to 999 kg</td>
<td>36%</td>
<td>vehicle 6 to 9 years old, manual worker</td>
</tr>
<tr>
<td>under 110 hp/t</td>
<td></td>
<td>man, leisure, petrol</td>
</tr>
<tr>
<td></td>
<td>from 800 to 999 kg</td>
<td>18 to 35, single petrol</td>
</tr>
<tr>
<td>110 hp/t and over</td>
<td>5%</td>
<td>vehicle 3 to 5 years old, loss of control,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>single vehicle, man</td>
</tr>
<tr>
<td></td>
<td>1000 kg and over</td>
<td>night</td>
</tr>
<tr>
<td>under 110 hp/t</td>
<td>24%</td>
<td>diesel, 36 to 64, married professional driver</td>
</tr>
<tr>
<td></td>
<td></td>
<td>man, vehicle less than 2 years old</td>
</tr>
<tr>
<td></td>
<td></td>
<td>hired or company car</td>
</tr>
<tr>
<td></td>
<td></td>
<td>non-local, executive, middle-class profession</td>
</tr>
<tr>
<td></td>
<td>1000 kg and over</td>
<td>professional, executive</td>
</tr>
<tr>
<td>110 hp/t and over</td>
<td>3%</td>
<td>vehicle less than 2 years old</td>
</tr>
<tr>
<td></td>
<td></td>
<td>craftsman, businessman, petrol</td>
</tr>
<tr>
<td></td>
<td></td>
<td>36 to 64</td>
</tr>
</tbody>
</table>

Table 1: over-represented characteristics in each group

In each category, the characteristics appear when their frequency in the class is significantly higher than the frequency in the whole of the population, but that does not mean that they are the main ones in the class.
3. Risk per kilometre covered

From our samples, we have evaluated the distribution of vehicles in accidents and in traffic (table 2).

<table>
<thead>
<tr>
<th>vehicle category</th>
<th>distribution of kilometres covered</th>
<th>distribution of vehicles in accidents</th>
</tr>
</thead>
<tbody>
<tr>
<td>under 800 kg</td>
<td>24.0%</td>
<td>31.5%</td>
</tr>
<tr>
<td>from 800 to 1000 kg under 110 hp/t</td>
<td>44.2%</td>
<td>36.3%</td>
</tr>
<tr>
<td>from 800 to 1000 kg 110 hp/t and over</td>
<td>2.2%</td>
<td>5.0%</td>
</tr>
<tr>
<td>1000 kg and over under 110 hp/t</td>
<td>27.8%</td>
<td>24.0%</td>
</tr>
<tr>
<td>1000 kg and over, 110 hp/t and over</td>
<td>1.8%</td>
<td>3.2%</td>
</tr>
<tr>
<td>all vehicles</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table 2: distribution in traffic and in accidents by class of performance and weight

The relative risk of being involved in an accident per kilometre covered has been calculated by taking a risk equal to 1 for the whole of the population studied. The power per tonne appears as a very discriminant criterion of risk, especially for the category of medium weights of 800 to 1000 kg. In spite of the small size of the sample for these high-powered and light categories, the over-risk is significantly higher than unity. The insurance companies also obtain this type of result for the categories of small high-powered vehicles (Besson, 1987).
Figure 1: relative risk per category of vehicles (risk = 1 for all)

Other criteria contribute, of course, to these estimates of risk, in particular the age of the driver and of the vehicle. It is known that there is an over-risk for young drivers and, to a lesser extent, for the oldest vehicles (Fontaine, 1988). This contributes to the over-risk observed for vehicles of under 800 kg. It would be necessary to carry out desegregated analyses according to the age of the drivers and the age of the vehicles, but this implies having available a larger sample, especially with regard to exposure.

4. PROTECTION AND AGGRESSIVENESS

We will firstly examine all accidents, then we will narrow down the analysis for accidents occurring between two cars and those involving a single vehicle and no pedestrian

4.1 All accidents

The internal and external rates of seriousness are represented in figure 2. The effect of weight on external seriousness is very clear: the level of external drivers and pedestrians killed increases with the weight of the vehicle. In internal seriousness, the effect of weight is less clear. The most protected group is that of low-performance heavy vehicles. Protection diminishes for the highest performance vehicles and, in particular, vehicles of average weight and of over 110 hp/t which present an internal seriousness significantly higher than that of the other categories. The over-representation of accidents involving single vehicles in this category explains at least in part, these results.
External seriousness is the number of external drivers and pedestrians killed per 1000 vehicles in the category. Internal seriousness is the number of drivers killed per 1000 vehicles in the category.

To eliminate a possible effect of the greater or lesser use of vehicles in towns, we have also analyzed the accidents which occurred exclusively outside built-up areas (figure 3), which increases overall seriousness.

Figure 2: internal and external seriousness for all accidents

Figure 3: internal and external seriousness for all accidents occurring outside built-up areas.
The effect of weight on the level of external seriousness is found again: the heaviest vehicles being the most aggressive, and the greatest protection is observed for the class of over 1000 kg and under 110 hp/t. The category of high performance vehicles and medium weight can be seen again by a high internal seriousness due probably to the relatively large number of accidents involving a single vehicle.

4.2 Two car collisions

For this type of accident, we take into account the striking vehicle (A) and the struck one (B). We use this terminology for clarification purposes, but it is obvious that the two vehicles play a symmetrical role in the analysis. This implies possessing the technical characteristics for each of the two vehicles involved, which reduces the size of the sample to about 17,000 vehicles. And if the 5 previously defined classes are retained, one obtains a squared table of 25 boxes some with very low numbers, even nil. We have therefore limited the analysis to 3 weight classes and to improve the reliability of the results, have taken both the drivers killed and the seriously injured into account.

Figure 4 shows the effect of weight on vehicle aggression: the bigger the striking vehicle, the greater the seriousness in the struck vehicle. In parallel, protection increases with the mass of the vehicle and the level of internal seriousness is in an inverse ratio to the weight of the vehicle. The overall level of seriousness is highest for accidents involving the heaviest vehicles.

![Figure 4: Drivers killed or seriously injured per 1000 cars by weight of the striking vehicle and of the struck vehicle.](image)

*Vehicles A and B play a symmetrical role in the analysis. The levels of seriousness for drivers are not significantly different for collisions between vehicles in the same weight category (dotted line).*
The analysis of collisions between vehicles in the same weight category does not show significant differences in the levels of drivers killed or seriously injured. Similar results are obtained by Thomas et al (1990) for drivers wearing seat belts who are involved in frontal collisions outside built-up areas. A German analysis (Ernst et al, 1991) shows, on the contrary, a reduction in the levels of seriousness of drivers as the weight increases in frontal collisions between passenger cars of the same mass and brings out the fact that the number of killed and seriously injured is lower in a crash between two heavy vehicles than in a crash between two light vehicles. This may come from the fact that the authors relate the number of victims to a number of personal and material accidents when the latter have caused high amount of damage. However, the heaviest vehicles are in general those which are driven more and are more expensive to repair. They are, therefore, over-represented in these types of accidents involving serious damage, a fact which, by increasing the denominator, reduces the ratio studied for these categories.

Note that by taking into account all serious accident victims, that is to say drivers and passengers, the severity rate increases with weight, in accidents between 2 vehicles in the same category. This is brought about mainly by different levels of occupation.

4.3 Single vehicle accidents

The analysis was carried out on a sample of 18,020 vehicles involved singly in accidents without pedestrians. The rate for the category of cars of medium weight and power per tonne of over 110 hp/t is significantly higher than the average. This group is, in addition, over-represented in this type of accident. Driver behaviour can be extracted only with difficulty from the statistical files, which is why it is important to have a more clinical approach based on detailed accident analyses. However, an attempt can be made to better isolate the effect of behaviour by differentiating the age of the driver.
4.4 The effect of the drivers age

The drivers age can be a factor at several levels: on the over-implication in certain types of accidents, insofar as young drivers are relatively more involved in losses of control for single vehicles but also on the resistance to shock which is however lower for elderly people. We have limited ourselves to an analysis of single cars without pedestrians. Figure 6 shows two types of results.

Elderly drivers are more vulnerable
The levels of seriousness for people of more than 65 are clearly higher than the average. This is also true for all accidents: 38 elderly drivers killed per 1000 cars involved as against 20 for the population as a whole. But insofar as this age group, which represents slightly less than 12% of drivers, is not part of the most discriminant criteria of our categories of vehicles, we consider that the influence on the results of seriousness is small.

The levels of severity for young drivers depends on the type of vehicle driven
Within the age class of young drivers, the difference in levels of seriousness according to the vehicle driven is much higher than for the 36 to 65 years category. So, when a driver aged under 25 changes from a vehicle of under 800 kg to a vehicle of 800 to 1000 kg and of over 110 hp/t, the level of seriousness increases by a factor of 1.6; and it doubles for the 26 to 35 age group. One finds here the effect of the interaction "young driver <-> high performance vehicle", which had already been observed in previous work. But it must be noted that the category of young drivers is not homogeneous (Biecheler-Fretel and Danech-Pajouh, 1987). It is difficult to identify the levels of risk "all things being otherwise equal".
Figure 6: drivers killed per 1000 vehicles in accidents with single vehicles

The length of the vertical lines indicates the confidence interval at 90%

5. CONCLUSION

This differential analysis has shown the over-risk of high-powered and light vehicles, taking into account the use made of them by their drivers. It also confirms the influence of the weight of the vehicles on their aggressiveness, as well as its protective role, but there appear no significant differences from the levels of severity of the drivers in collisions between two cars of the same category of weight. A specific effect of the vehicle performance on the internal seriousness has been noted and the category of cars of medium weight and high power per tonne presents a particularly bad overall total of seriousness (internal and external).

The age of drivers has an effect at two levels. Elderly people are more vulnerable and their levels of seriousness are higher than the average; and young drivers are more sensitive to the type of vehicle driven both in terms of involvement in certain categories of accidents and in terms of growth of the seriousness with the performance of the vehicle driven.

The influence of the "vehicle-driver" combination appears clearly through these results and shows the need to carry out desegregated analyses. The next survey on
transport which will take place in France, in 1993, should give more complete and more reliable information on distances covered through vehicle-linked car log books. It will thus be possible to evaluate the exposure to risk in a sharper way and therefore to take into account the respective influence of the factors linked to drivers, vehicles and the network, in an explanatory analysis of the driving risk.

ACKNOWLEDGEMENTS

The author would like to thank the "Assemblée Plénière des Sociétés d'Assurance Dommages" and the "Service d'Etudes Techniques des Routes et Autoroutes" who have supplied the data necessary for this work, as well as Yves Gourlet, Jean-Claude Jurvilliers and Isabelle Saint-Saens of INRETS who set up the databases.

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VTI RAPPORT 380A
Motor Vehicle Inspection
Its Importance for Road Safety

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VEHICLE INSPECTION - ITS IMPORTANCE FOR ROAD SAFETY

In Norway, motor vehicles are inspected both by means of random, roadside inspections and by means of periodic inspections. An experiment was conducted during the years 1986-1990, in order to estimate the effects of periodic inspections on automobile accident rates. A total of 265,000 cars took part in the experiment. These were randomly assigned to three groups. One group was inspected annually for three years, one group was inspected in 1986 only and the group was not inspected at all. Effects on accident rates and technical condition were measured. In addition, unintended side-effects of the experiment were controlled for in order to make sure that the results could be attributed to vehicle inspections, not other factors.

Toward the end of this experiment, another study was started with the purpose of developing a more effective system of vehicle inspections. A problem encountered in periodic inspection is that a large proportion of the cars that are inspected have no technical defects. These cars really do not have to be inspected.

A random sample of 5,000 cars are stopped in traffic and referred to the nearest inspection hall of the Department of Motor Vehicles, where their technical condition was determined by means of an ordinary inspection.

Subsequent analyses uncovered the relationships between technical condition and a number of variables recorded in the motor vehicle registration file, like age of car, make and model, and sex and age of the owner.

Based on the results of these analyses, a preliminary computer programme was written that will make it easier to select vehicles that are likely to have technical defects for inspection.
1. INTRODUCTION

1.1 Motor vehicle inspection in Norway

Norway has an extensive programme for technical inspection of motor vehicles. There are two types of inspection: periodic motor vehicle inspection and random, roadside inspection. The main objective of the inspections is to reduce the number of road accidents.

Periodic inspection is conducted by the State Department of Motor Vehicles. Car owners receive by mail an appointment card for inspection. The vehicle must be presented for inspection within six weeks from receipt of the appointment card. Inspection is conducted in one of the inspection halls of the Department of Motor Vehicles, or at a licensed garage. In 1989, about 150,000 cars (passenger cars and vans) were inspected. This constitutes about 9-10% of all cars in Norway. In addition about 285,000 cars were inspected in roadside inspections (Statens Vegvesen, 1990).

If technical defects are found during inspection, car owners are required to repair the defects within two weeks. Vehicles will normally be re-inspected in order to check that defects have been repaired. Failure to present a vehicle for re-inspection may lead to revocation of license plates, in effect banning the use of the vehicle on public roads.

In 1987, periodic motor vehicle inspections cost the Department of Motor Vehicles about 40 million Norwegian kroner (corresponding to about 6 million US Dollars at the 1987-exchange rate) (Steinbru, 1988). This figure does not include car owner costs, for example the costs of travel time, repair costs or the economic value of potential changes in vehicle longevity as a result of inspections.

The annual, societal costs of road accidents have been estimated at about 9 billion Norwegian kroner (Hagen, 1991). This means that the costs incurred by
the Department of Motor Vehicles in conducting inspections correspond to about 0.5% of the total, annual cost of accidents.

About 10% of all cars are inspected each year. This means that the accident cost generated by these cars must be reduced by at least 5% during the first year after an inspection, in order for the inspection to have a benefit-cost-ratio above the value of 1.0. Such a reduction can be accomplished by reducing the accident rate, reducing the severity of accidents, or both.

1.2 Does periodic motor vehicle inspection improve safety? A review of previous research

The number of technical defects increases as cars become older (Fosser & Ragnøy, 1991). The accident rate of cars also increases with car age (Elvik, Vaa & Østvik, 1989). It is nevertheless not known if the increase in accident rate for old cars is caused by technical defects or other factors. Car age is associated with owner age, i.e., old cars are often owned by young owners (Fosser & Ragnøy, 1991). Driver age is related to accident rate (Elvik, Vaa & Østvik, 1989).

A number of studies have been reported on the effectiveness of periodic motor vehicle inspection in preventing accidents:

Sweden introduced mandatory annual inspection of all cars in 1966. A time-series analysis covering the years 1955-1981 (Berg, Danielsson & Junghard, 1984) concluded that the number of cars involved in police reported accidents declined by 14 per cent following the introduction of annual inspections. The number of injury accidents declined by 15 per cent. The number of injured persons declined by 9 per cent and the number of property-damage-only accidents by 3 per cent. These latter two changes were not statistically significant.

The state of New Jersey introduced periodic motor vehicle inspection in 1938. A time-series analysis covering the years 1929-1979 (Loeb & Gilad, 1984) concluded that periodic motor vehicle inspection in New Jersey reduced the number of fatalities as well as the number of accidents. The number of injured persons was not significantly affected.

There are a number of uncertainties in these time-series analyses. During a period of more than 25 years, several factors that affect the number of accidents can be expected to change, some of them in the direction of increased safety. The accident rate per unit distance of driving very often declines as traffic volume in a country increases. Roads become safer, cars become safer and traffic management is improved. The Swedish study tried to take account of some of these factors, like changes in the use of seat belts, daytime running lights and traffic volume. The true effect of all these factors is, however, unknown. In addition, the change to right-hand driving took place at about the same time as periodic motor vehicle inspection was introduced (in 1967). It
must be concluded that these two studies have not been able to isolate the effect of periodic motor vehicle inspection from potential confounding factors.

Two studies conducted in The United States compared accident rates in states with periodic motor vehicle inspection to accident rates in states without (Crain, 1980; VanMatre & Overstreet, 1982). Crain (1980) did not find any statistically significant differences in fatality rates between states with periodic motor vehicle inspection and states without it. There was a non-significant tendency toward higher fatality rates in states with periodic motor vehicle inspection. VanMatre & Overstreet (1982), on the other hand, found that the fatality rate per 100,000 inhabitants was about 10 per cent lower in states with periodic motor vehicle inspection than in other states. None of the studies took fully account of other relevant differences between the states that were compared. It cannot be ruled out that states which have introduced periodic motor vehicle inspection have more efficient road safety policies in other ways as well. If that is the case, a difference in accident rates might just as well have been caused by other road safety measures.

A multivariate study, based on econometric modelling, tried to estimate the effect of periodic motor vehicle inspection on US fatality rates by using data from all fifty states (Robinson, 1989). 29 states had periodic motor vehicle inspection, 9 states had a system of random inspections and 12 states had no system of motor vehicle inspection. The study tried to take account of factors like differences in driver behaviour, traffic regulations and vehicle characteristics. It was concluded that no effect of periodic motor vehicle inspection on fatality rates could be detected. While relying on a far more sophisticated design than a number of other studies, even this study may have an omitted variable bias. The effective sample size was only 50, making it difficult to reach statistically significant conclusions.

A controlled before-and-after study, in which six US states formed the experimental group and various groups of other states formed control groups (Little, 1971), found that the fatality rate per 100,000 inhabitants increased following the introduction of periodic motor vehicle inspection. The use of control groups is an advantage of this study, compared to a simple before-and-after study or a simple with-and-without comparison. Nevertheless, the differences found between test and control states were not necessarily caused by the introduction of periodic motor vehicle inspection alone. The introduction of periodic motor vehicle inspection may be easier to accomplish in favourable economic circumstances than it is otherwise. A high rate of economic growth may lead to growth in traffic volume and, subsequently, in the number of road accident fatalities.

Another US study (Schroer & Peyton, 1979) found that the average accident involvement rate of cars which were inspected was about 9 % lower during the first year after inspection than for cars not inspected. The difference vanished gradually and was not detectable after one year. In this study, the inspected cars
had volunteered for inspection. Hence, the possibility of a self-selection bias cannot be ruled out.

In New Zealand, all cars are inspected every half year (White, 1986). A study of week-by-week changes in accident rates over the year, found that accident rates were at their lowest immediately after an inspection. During the next six months, accident rates increased by about 10-15 %, reaching a peak immediately before the next inspection. The data used in this study were, however, not of an ideal quality, according to the author (White, 1986).

The overall impression from previous research is that results diverge and that a general conclusion regarding the safety effects of periodic motor vehicle inspection is difficult to reach. All reported studies have some kind of methodological weakness, though not always of the same nature. Some studies find a favourable safety effect, others no effect, still others indicate a negative effect. It is impossible to reach a general conclusion.

2. PURPOSES OF THE STUDY

The purpose of the study reported in this paper was to determine if periodic motor vehicle inspection, as it is done in Norway, reduces accident rates and/or the severity of accidents. Another purpose was to estimate the size of an effect, if present, and to determine how it varied according to vehicle age. The duration of an effect was also to be determined. In addition, the study was designed to detect the effects of periodic motor vehicle inspection on the technical condition of vehicles.

3. A MODEL OF THE EFFECTS OF PERIODIC MOTOR VEHICLE INSPECTION

The study relied on a model of the effects of periodic motor vehicle inspection. This model is depicted in figure 1.
In figure 1, curve a) shows how the accident rate of cars kept in good order, for example by means of very frequent technical inspections, may change as the cars become older. Curve b) shows the corresponding changes for cars which are allowed to acquire technical defects. Curve c) shows the effects of annual technical inspections. Curve d) shows the effects of inspections every third year. Curve e) shows the scrapping level of cars, that is the worst technical condition a car acquires before it is scrapped. Curve f) indicates the accident rate of new cars.

The model is based on the assumption that technical inspections improve technical condition. Improving technical condition subsequently leads to fewer accidents. In other words, the worse the technical condition of a car, the higher its accident rate.

Curve a) represents the best possible development of the accident rate throughout a car's service life. A car following this path of development is kept in perfectly good order. No technical defects are permitted to develop. By definition, such cars will not become involved in accidents due to technical defects. Their technical condition will nevertheless deteriorate, as vehicle components are worn during normal use.
Curve b) shows how accident rates might develop in a situation without any technical inspections. The technical condition will gradually get worse, and the accident rate increase accordingly. The curves a) and b) form the limits between which accident rates may vary as a result of periodic motor vehicle inspection.

For cars inspected annually, a pattern like the one shown by curve c) might be envisaged. Cars inspected less frequently, like every third year, might be envisaged to follow the pattern shown by curve d).

Curve e) shows the scrapping level. It appears reasonable to assume that cars inspected frequently will reach this level later than cars not inspected. This will prolong the service-life of cars. Curve e) is not horizontal, as the scrapping of cars could be affected by other factors, not just the frequency of technical inspections.

During the service-life of a car, new cars are introduced every year with additional safety features. This means that new cars are gradually becoming safer, as indicated by the downward slope of curve f). The fact that the service-life of cars may be prolonged may therefore negatively affect safety in general.

Figure 2 indicates how the total effect of periodic motor vehicle inspection can be decomposed into a positive component and a negative component.
The positive component, contributing to fewer accidents, is shown by the shaded area covered by a plus sign. This component is present until the mean age at which cars would be scrapped in the absence of periodic inspections. Beyond this age, periodic motor vehicle inspection may lead to more accidents, by keeping old cars in service instead of replacing them by new and safer cars.

4. PROBLEM STATEMENT

Based on the model and knowledge of the present system of periodic motor vehicle inspection in Norway, the following questions were asked:

1. Does periodic motor vehicle inspection reduce the risk of becoming involved in road accidents for cars which undergo such inspection, and if so what is the best estimate of the size of the effect?

2. Does the effect of periodic motor vehicle inspection vary according to the age of the car? How long does the effect last?

3. Does the effect of periodic motor vehicle inspection vary according to the frequency of inspections?

4. Does periodic motor vehicle inspection affect the severity of accidents?

5. Does periodic motor vehicle inspection prolong the service-life of cars?

The size of any effect of periodic motor vehicle inspection on the risk of accident is likely to depend on the size of its effect on technical condition. In addition to estimating the effects on accident rates, the study was designed to estimate the effects on technical condition.

5. METHOD

5.1 Experimental design

As illustrated in the review of previous studies, there are many pitfalls in evaluating the effect of periodic motor vehicle inspection on accident rates. In order to avoid these pitfalls, it was decided to conduct an experiment. The purpose of the experiment was to compare the effects of annual inspection, and inspection every third year to a control condition of no inspection.

The experiment started in 1986 and ended in 1990. It comprised cars registered in Norway for the first time in 1978, 1979 and 1980. These model years were chosen as a compromise between two considerations. On the one
hand, as few cars as possible should get scrapped during the experiment, in order to avoid a loss of data. On the other hand, the cars should be old enough to have developed technical defects.

The sample size was determined so as to have the power to detect a 3 per cent difference in annual accident rates at the 5 per cent level of statistical significance. This required a sample of several thousand cars in each group. Data on accidents were provided by four major insurance companies in Norway, with a combined market share of 80-90 per cent. Most of the accidents recorded by the insurance companies are property-damage-only accidents.

The study was confined to passenger cars and vans, from now on referred to as cars. In order to be eligible for inclusion in the experiment, a car had to satisfy the following requirements:

1. The car should not have been inspected during 1985.
2. The car should be insured in one of the four major insurance companies.
3. The car should be of model year 1978, 1979 or 1980.
4. Taxis and cars used for driver training were excluded.
5. The car should not be scrapped, or its license plates revoked, at the start of the experiment.

There were altogether 204,000 cars satisfying these requirements. All these cars were included in the experiment. The cars were randomly assigned to the following three different experimental conditions:

1. Group 1: Cars inspected annually. This group comprised 46,422 cars at the start of the experiment. These cars were inspected in each of the years 1986, 1987 and 1988.
2. Group 2: Cars inspected once during three years. This group comprised 46,422 cars at the start of the experiment. The cars were inspected in 1986 only.
3. Group 3: Cars not inspected. These formed the control group of the experiment. It comprised 111,412 cars at the start of the experiment.

The random assignment of cars to the three groups ensured that these were identical in all relevant respects at the start of the experiment.
5.2 Accident periods

The accident experience of each car was monitored for three one-year periods following technical inspection. Figure 3 indicates how the accident periods were defined.

<table>
<thead>
<tr>
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<th></th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>PMVI every 3 years</td>
<td>46.422</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No PMVI</td>
<td>111.412</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In order to get comparable accident periods for cars not inspected (group 2 during 1987 and 1988 and group 3 during the whole experiment), a fictitious inspection date was computed on the basis of the known inspection dates of cars which were inspected. These fictitious dates were used as starting dates of the accident periods for these cars, which were also of one year.

Cars which were supposed to have been inspected, but were in fact not inspected, have been given a fictitious inspection date in the same manner.

5.3 Controlling unintended side-effects of the experiment

Experiments can have unintended side-effects. It was therefore decided to design the experiment so that any such effects could be detected and taken account of during analysis.

Here is an example of an unintended side-effect which might occur: Owners of cars included in the experiment could, at the outset, not choose by themselves...
whether their car should be included or not. Yet they might opt out of the experiment by selling the car, once they learnt that it was part of an experiment and was going to be inspected each year for the next three years.

It was virtually impossible to predict whether any unintended side-effects would in fact occur and what their effects might be. Planning for this contingency therefore consisted of requiring the insurance companies to provide detailed data about each car, including for example age and sex of the owner, annual driving distance and change of ownership, in addition to accident data.

The insurance companies did not know which experimental group each car belonged to.

5.4 Information to car owners

If a system of annual inspections had been introduced in Norway, car owners would know this and adjust to it. It was therefore decided that owners of cars assigned to groups 1 and 2 be informed that their car took part in an experiment. This information was given on the appointment card for inspection sent by mail. In view of the fact that only about 10 per cent of all cars are subjected to periodic inspections every year, it was decided that no extra information needed be given to owners of cars assigned to group 3. A brief press statement was, however, sent at the start of the experiment.

5.5 Additional sample for studying the effects of periodic motor vehicle inspection on technical condition

In 1987, 1988 and 1989 a sample of about 1,500 cars was drawn from each experimental group in order to study the effects of periodic motor vehicle inspection on the technical condition of vehicles. All cars included in this sample were inspected, including those assigned to the control group. The subsample was drawn within each group.

Some car owners repair their car before presenting it for technical inspection. Owners of cars belonging to the subsample drawn for studying technical condition were given a questionnaire on which they could indicate what kind of repairs, if any, they had done before presenting the car for inspection.

5.6 Statistical testing of results

The accident rate (risk of accident per car) estimated for each car is an annual average value.

For each group, the mean accident rate of cars assigned to the group was estimated. A confidence interval for each mean value was estimated by
assuming that the number of accidents is Poisson-distributed. The same assumption was made when testing differences between two accident rates. It was assumed that exposure (car days), is measured with certainty. Hence, the confidence intervals take account only of random variation in the number of accidents. In comparing the groups with respect to other variables (than the accident rate), Chi-square tests were used. Some of the results refer to calendar years, not to the first chronological year after an inspection (or a fictitious inspection date). This was mainly done to facilitate analysis, but is practically immaterial for the substance of the results.

6. RESULTS

6.1 The effect of periodic motor vehicle inspection on accident rates

The number of accidents per 1,000 car days was estimated for each group during each of the three one-year accident periods. Table 1 shows the results.

<table>
<thead>
<tr>
<th>Period</th>
<th>Cars inspected annually</th>
<th>Cars inspected in 1986</th>
<th>Cars not inspected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 1</td>
<td>0.322</td>
<td>0.309</td>
<td>0.314</td>
</tr>
<tr>
<td>Year 2</td>
<td>0.322</td>
<td>0.316</td>
<td>0.318</td>
</tr>
<tr>
<td>Year 3</td>
<td>0.292</td>
<td>0.298</td>
<td>0.290</td>
</tr>
</tbody>
</table>

There were no statistically significant differences between the three groups in any of the three accident periods. The results indicate that neither annual inspection, nor inspection every third year, had any effect on the accident rate of the cars included in the study.

6.2 The effect of periodic motor vehicle inspection on the severity of accidents

For each group, the following statistics intended to describe the severity of accidents were computed: (1) The percentage of all reported accidents involving personal injury, (2) Mean repair costs for damages to other vehicles or other property, (3) Mean repair costs for damages to the owners' own car. Table 2 shows these statistics for each group.
Mean values for all years

<table>
<thead>
<tr>
<th>Severity statistics</th>
<th>Cars inspected annually</th>
<th>Cars inspected in 1986</th>
<th>Cars not inspected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Per cent of accidents with personal injury</td>
<td>3.1</td>
<td>2.8</td>
<td>3.1</td>
</tr>
<tr>
<td>Repair costs for damages to other vehicles or property</td>
<td>3949</td>
<td>3903</td>
<td>4080</td>
</tr>
<tr>
<td>Repair costs for damages to the owners car</td>
<td>4558</td>
<td>4501</td>
<td>4514</td>
</tr>
</tbody>
</table>

Table 2 shows no statistically significant differences between any of the groups for either of the three measures of accident severity. Apparently, periodic motor vehicle inspection does not affect accident severity.

6.3 The effect of periodic motor vehicle inspection on the service-life of cars

Table 3 shows the cumulative percentage of the original sample of cars which had been scrapped by the end of 1986, 1987, 1988 and 1989.

<table>
<thead>
<tr>
<th>Year</th>
<th>Cars inspected annually</th>
<th>Cars inspected in 1986</th>
<th>Cars not inspected</th>
</tr>
</thead>
<tbody>
<tr>
<td>1986</td>
<td>0.60</td>
<td>0.59</td>
<td>0.59</td>
</tr>
<tr>
<td>1987</td>
<td>1.72</td>
<td>1.61</td>
<td>1.79</td>
</tr>
<tr>
<td>1988</td>
<td>3.81</td>
<td>3.60</td>
<td>3.94</td>
</tr>
<tr>
<td>1989</td>
<td>6.10</td>
<td>6.12</td>
<td>6.58 *</td>
</tr>
</tbody>
</table>

* Statistically significant difference at 1%

The results indicate that periodic motor vehicle inspection may prolong the service-life of cars. At the end of the experiment, significantly more cars had been scrapped in the control group than in either of the two test groups. It is, however, not possible to estimate how much service-life is prolonged, as few cars had been scrapped, even in the control group, at the end of the experiment.
7. DISCUSSION

There are several possible explanations to the finding that periodic motor vehicle inspection does not affect accident rates. These are briefly discussed below.

7.1 Were all cars inspected?

About one third of the inspections which were supposed to have been performed were in fact not carried out. Reasons for this include roadside inspections, changes of ownership, inadequate capacity in the Department of Motor Vehicles, etc. The shortfall did not show any systematic pattern. If an effect had been found, the shortfall of inspections would have diluted it.

7.2 Were there any unintended side-effects of the experiment?

Even if the three groups of cars were identical at the start of the experiment, differences may have arisen during its course, e.g., with respect to insurance, driving distance or frequency of ownership changes. Such differences might influence both the number of accidents and the probability of their being reported. An investigation was made into these potential side-effects of the experiment.

No differences were found between the three groups with respect to frequency of ownership changes, owner age or owner sex. Besides, there were no differences concerning annual driving distance, percent holding collision insurance and the deductible part of collision insurance.

There is, therefore, no reason to believe that the experiment has affected the three groups differently in any other way than by way of the frequency of inspections. There is a firm basis for concluding that periodic motor vehicle inspection did not reduce the accident rate of the inspected cars.

7.3 The effects of periodic motor vehicle inspection on technical condition

Periodic motor vehicle inspection in Norway is conducted by means of an inspection checklist consisting of 63 items. For each item, the inspector checks whether the item is defective or not. The items include most vehicle components and functions, except engine and power train.

Figure 4 shows the mean number of technical defects per car for each of the three groups in 1988 and 1989.
There were significantly more defects per car for cars not inspected than for the two test groups. Cars inspected annually had significantly fewer defects than the other two groups (test group 2 and the control group). The number of defects increases as more time passes since the last inspection.

Technical defects found on cars in group 1 have been repaired. Otherwise the car would not pass the inspection, and would be instructed to appear for repeated re-inspection until all defects were repaired. Figure 4 indicates how the number of defects may have changed during the time between two successive inspections.

The results presented in figure 4 conform to what was expected on the basis of the model presented in figure 1. The most marked differences were found for headlights, brakes and shock absorbers. There was also a tendency in the expected direction for defects to steering, parking brakes and miscellaneous other items. It was only with respect to wheels that no difference could be detected between the groups in terms of the mean number of defects per car. The results are uncertain, being based on a much smaller sample than the results referring to accident rates. But there is no doubt that periodic motor vehicle inspection does improve the technical condition of inspected cars.

The answers car owners gave to the questionnaire concerning their own repair activities indicated that owners of cars assigned to the control group repaired more defects before presenting the car for inspection than owners of cars in the two test groups. The difference was, however, not statistically significant.
Overall, the results clearly indicate that periodic motor vehicle inspection improves the technical condition of vehicles. But the improvement does not last very long. After one year, there is only a small difference between a car which has been inspected and one which has not been inspected.

7.4 The relationship between technical condition and accident rate

When inspections improve technical condition, but does not reduce the accident rate, this means that the differences in technical condition between inspected and non-inspected vehicles is unrelated to safety. This could have two explanations. Either the technical defects do not affect vehicle performance in any ways which are important to safe driving, or drivers compensate for known technical defects by driving more carefully. Compensatory behaviour includes driving more slowly or raising attention level, thus preventing the number of accidents from increasing.

7.5 The possibility of a preventive effect from the existence of a system of periodic inspections

Periodic motor vehicle inspection may have a preventive effect, by inducing car owners to maintain their cars properly. If such a preventive effect exists, its consequence is that cars in the control group have fewer technical defects today than they would have if periodic motor vehicle inspection did not exist. Such an effect, if it exists, cannot possibly have influenced the results of this study to any major extent. None of the cars had been inspected in 1985. Before 1985, the cars were so new that very few of them are likely to have been inspected at all. Moreover, it is likely that the existence of roadside inspections has more of a preventive effect. Periodic inspections give the owner ample time repair defects before presenting the car for inspection. Roadside inspections offer no such opportunity. On the contrary, they offer the risk of having the car banned from being used instantly. It is therefore highly unlikely that periodic motor vehicle inspection has any preventive effect above the one generated by the existence of roadside inspections.

8. CONCLUSIONS AND FURTHER RESEARCH

This study clearly shows that periodic inspection of cars that are less than 12 years old improves technical condition, but has no effect on accident rates or accident severity. There is a tendency for periodic inspection to prolong the service-life of cars.

The explanation to these findings is not fully known, but two theories can be proposed:
1. Drivers compensate for poor technical condition, or for the fear of such a condition, leaving the number of accidents unaffected.

2. The differences in technical condition between cars included in this study were too small to have any practical importance for road safety.

8.1 The total effect of periodic motor vehicle inspection

If drivers compensate for a poor technical condition, then neither improving this condition nor speeding up the turnover rate in the vehicle fleet need affect the number of accidents. The safety features of new cars, like seat belts, head rests, airbags and energy-absorbing parts in the front and rear of the body of the car primarily reduce the severity of occupant injuries once an accident has occurred. Their effect on the probability of accident occurrence is less obvious (Elvik, Vaa & Østvik, 1989). Evidence suggests that drivers do not compensate for injury-reducing safety features to the same extent that they compensate for more active safety features, like improved steering or road-holding properties.

It is therefore reasonable to hypothesize that, even if the number of accidents is unrelated to car age, the risk of injury granted that an accident has occurred will be lower in new cars than in old cars. If cars are turned over faster, this hypothesis implies that there could be a net safety benefit.

If, on the other hand, drivers do not compensate for technical condition, it would seem reasonable to hypothesize that cars in poor technical condition have higher accident rates than cars in good technical condition.

This means that if periodic motor vehicle inspection slows down the turnover rate of the car fleet, the net effect on the risk of personal injury could be negative irrespective of whether drivers compensate for poor technical condition or not.

8.2 The benefits of improving technical condition

Periodic motor vehicle inspection improves technical condition, but not safety. This means that improving the technical condition of vehicles in Norway beyond the level of cars in the control group will not improve road safety. Neither stepping up periodic inspections nor stepping up roadside inspections is likely to have any effect on safety. Furthermore, it is unlikely that abolishing periodic inspections for cars that are less than 10-12 years old will affect safety in Norway negatively.
8.3 Generalization of the results beyond the range of variability observed

The experiment showed that improving technical condition above the level of cars in the control group did not improve safety. In addition, there was no tendency for accident rate to increase as cars became older, despite the fact that the number of technical defects increased. It can nevertheless not be ruled out that periodic motor vehicle inspection could improve safety for cars that are older than the oldest cars included in this experiment, i.e., older than 10-12 years.

It is, after all, likely that the technical condition of a vehicle will eventually affect its safety, but perhaps not until much more serious defects have developed than those found in this study. If drivers compensate, the risk of accident will start to increase only when the technical defects get so grave that drivers are unable to compensate for them. A model indicating a possible relationship between technical condition and accident rate is shown in figure 5.

![Graph showing accident rate vs. technical condition with PMVI and no PMVI conditions]

Figure 5 indicates that periodic motor vehicle inspection does not affect accident risk, because the technical condition of vehicles remains rather good even in the absence of periodic motor vehicle inspection. Even if accident risk increases as technical condition deteriorates, a corresponding increase in the number of accidents may not ensue. Perhaps cars in the worst technical condition will be driven less than other cars.

It is probable that for periodic motor vehicle inspection to have any effect on the number of accidents, cars must be in a far poorer technical condition than the cars included in this study. While such a possibility cannot be ruled out, the
precise level of technical condition at which periodic motor vehicle inspection makes sense from a road safety point of view cannot be determined from this study.

8.4 Generalization of results to other countries

In considering practical conclusions from this study, its limitations should be borne in mind. The study was conducted in a system where random, roadside inspections exist alongside periodic inspections. In addition, car owners may choose to keep their vehicles in good order irrespective of any scheme of technical inspections, in order to avoid loss of market value and driving discomfort. Perhaps such factors exert such a major influence on vehicle maintenance that the additional contributions from a scheme of inspections are negligible and inspection unnecessary.

None of the previous studies reviewed in the introduction were experimental. The results of these studies are uncertain, since the possibility that methodological flaws influenced them cannot be ruled out. The present study has tried to rule out such a possibility so far as possible. In a previous study (Fosser & Nedland, 1987), the possibility of generalizing the results of the present study to other Scandinavian countries was discussed. It turned out that there are major differences between the Scandinavian countries with respect to the number of cars annually subjected to periodic motor vehicle inspection. On the other hand, the checklist used during inspections is very similar in all countries. The results of the present study indicate that the other Scandinavian countries could obtain similar results to Norway as far as technical condition is concerned by scaling down periodic inspections and combining a scaled down version with roadside inspections.

8.5 Limitations of the study

It cannot be ruled out that periodic inspection of cars that are older than 10-12 years, or of buses and trucks, could benefit safety. In particular, trucks are sometimes operated far closer to the "safety margin" than cars. Further research is needed in order to clarify the relationship between technical condition, inspections and accident rate for heavy vehicles.

This study was limited to the safety effects of periodic motor vehicle inspection. It does not say anything about the effectiveness of inspecting cars in order to check engine emissions and noise levels. From an environmental point of view, such inspections may be valuable. In addition, periodic motor vehicle inspection can have other effects, like reducing vehicle operating costs. Such
effects may be important in a cost-benefit analysis, although not addressed in this study.

8.6 Further research

After completion of this experiment, a survey of the technical condition of cars in traffic has been made. 5,000 cars were stopped in a roadside survey and directed to the nearest inspection hall. Data was obtained on technical condition and a number of variables believed to affect technical condition, like age and sex of owner, car make and model year, frequency of previous changes of ownership and frequency of previous inspections. The purpose of collecting these data was to make inspections more effective. A multiple regression analysis was performed in order to find the relationship between technical condition and a number of explanatory variables. On the basis of this analysis, a formula was developed, enabling the Department of Motor Vehicles to estimate the expected number of technical defects before inspecting a vehicle, and using this estimate as a basis for selecting vehicles for inspection. It is hoped that by relying on this procedure, selecting vehicles with few or no technical defects for inspection can be avoided. The model is currently being tested in two counties in Norway.

It is important to find out whether the absence of an effect on safety of periodic motor vehicle inspection is caused by driver compensation or if it simply means that technical condition, or, more precisely, the change in technical condition brought about by an inspection, is unrelated to safety.

In order to answer this question, another experiment is desirable. By relying on the formula described above, a sample of vehicles in very poor technical condition can be drawn. This sample might then be randomly divided into two subsamples. Cars in one of the subsamples are then inspected once or twice a year. Cars in the other subsample are not inspected and constitute the control group. By collecting data on accidents and other outcome variables, as well as technical condition, the importance of technical condition for safety can be determined.

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STATENS VEGVESEN:

STEINBRU, A.:

VAAJE, T.:

VAN MATRE, J. G. & OVERSTREET, G. A.:

WHITE, W. T.:
On Stability of Four-Wheel Drive Motor Vehicles of Categories M₁ and N₁

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(not present at the conference)
ON STABILITY OF FOUR-WHEEL DRIVE MOTOR VEHICLES
OF CATEGORIES M1 AND N1

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Steerability and stability are two of the most important properties of motor vehicles as concerns the possibility of preventing accidents.

The road accident statistics confirm the necessity to improve reliability of the "driver-vehicle" system.

The safe operation of motor vehicles depends on the great deal of factors.

The current EEC Regulation No. 79 "Uniform Provisions Concerning the Approval of Vehicles with Regard to Steering Equipment" contains the minimum number of requirements for the steering control effort, the steered wheel stabilization and the vehicle manoeuvrability necessary for the safe travel on the public roads.

With a view to standardizing the test methods a number of standards and draft standards has been worked out by ISO for regulating test conditions: steady state circular test procedure (ISO 4138); lateral transient response test methods ("step input") (ISO 7401); braking in a turn (ISO 7975); the test procedure for a severe lane-change manoeuvre (ISO 3888); etc.

The whole complex of measuring individual parameters of motor vehicle travel and steering influence values in these tests does not allow to give the comprehensive assessment of stability and steerability.

The analysis of the ISO standardization documents has shown that the basic evaluation index when executing manoeuvres is the average maximum speed at which the prescribed track sections are passed.

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At that, throughout the manoeuvre the driver must maintain the maximum possible speed while controlling the fuel supply, that makes the obtaining results far too subjective.

The tests on stability of the four wheel drive motor vehicles of categories M1 and N1 have been carried out at the Central Automotive Proving Ground to work out the standardization document regulating test methods, requirements for their results, and allowing to determine if the motor vehicles of those categories may be permitted to be used on the public roads.

The test procedure the following necessary kinds of tests:

- determination of the lateral stability on the tilt test rig;
- determination of the driving stability when executing the following manoeuvres: turning at \( R_t = 35 \) m and lane-changing at \( S_{1c} = 12-24 \) m.

Marking of the test sections is shown in fig. 1 and 2.

The standardized values of parameters are given the conformity to which makes it possible to evaluate the following:

- the tilt platform angle at which the wheels on one side of the motor vehicle lifted;
- the roll angle of the sprung mass;
- the limiting speeds during execution of the "turning" and "lane-change" manoeuvres.

The standardized values are given in Table 1.
<table>
<thead>
<tr>
<th>Stability characteristics of motor vehicles</th>
<th>Motor vehicle category M₁</th>
<th>N₁</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tilt platform angle relative to horizontal at which all the wheels on one side of motor vehicle lifted, degrees</td>
<td>not less than 40</td>
<td>not less than 40</td>
</tr>
<tr>
<td>Roll angle of sprung mass in motor vehicle section passing through the centre of mass,</td>
<td>not more than 6.5</td>
<td>not more than 6.5</td>
</tr>
<tr>
<td>Limiting speed $V_{lim1}$ when executing manoeuvre &quot;Turning&quot;, $R_t = 35$ m, km/h</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limiting speed $V_{lim2}$ when executing manoeuvre &quot;lane-change&quot;, km/h</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$S_{1c} = 12$ m</td>
<td>not less than 50</td>
<td>not less than 46</td>
</tr>
<tr>
<td>$S_{1c} = 16$ m</td>
<td>not less than 62</td>
<td>not less than 56</td>
</tr>
<tr>
<td>$S_{1c} = 20$ m</td>
<td>not less than 74</td>
<td>not less than 66</td>
</tr>
<tr>
<td>$S_{1c} = 24$ m</td>
<td>not less than 86</td>
<td>not less than 76</td>
</tr>
</tbody>
</table>
Decreasing in kinds of tests or number of standardized parameters will not allow to get the distinct answer concerning the permission for motor vehicles to be used on the public roads. This statement is based on the large experimental material available in Russia.

The main feature of the proposed method of assessment is the simulation of emergencies which could lead to accidents:
- lateral overturning;
- the safe speed exceeded when entering a turn;
- the lane-change because of a sudden obstacle.

The tests conducted under the accepted at the Automotive Proving Ground test methods of the number of full leaded four drive motor vehicles of category M1, such as Scout-P, Nissan Patrol, Jeep Cj-7, Suzuki-410, the Ulyanovsky Automobile Plant's "Martorelli", as well as some other native motor vehicles of that category, allowed to get the results defining their stability and steerability (see table 2).

In particular, the lateral stability factors were defined:

\[ g_s = \frac{K}{2h} \]

where: K - track; h - height of the centre of mass.

When ballasting the motor vehicle with the water-filled dummies on the passengers' and driver's seats and with sand bags in the luggage space, the \( g_s \) values made up 0.97-1.25.

The tilt degree of the test rig platform for the same vehicles ranged from 43° to 48°.

One of the most important indices is the roll angle of the sprung mass relative to the supporting surface. This index as well as the tilt platform angle is subjected to standardization and at \( g_s > 1 \) must not exceed 6.5°.

As the test results have shown, that angle of one of the test motor vehicles, the Japanese Suzuki-410, was as high as = 8.5°, which we think is indicative of its insufficient lateral overturning stability.
Additional tests of that motor vehicle with executing the manoeuvres "turning at \( R_t = 35 \text{ m} \)" and "lane-changing at \( S_{lc} = 24 \text{ m} \) gave a confirmation to its being apt to overturn at speeds close to the limiting one. The driving stability of Suzuki-410 was assessed as unsatisfactory.

The limiting speed values of the most test vehicles have been restricted by slipping (motor vehicles being apt to be oversteered).

Assessment of static overturning stability as well as driving stability in each of the simulated situations ("lane-change" and "turning") is carried out by comparing to the standardized reference values the conformity to which ensures the required driving stability level.

This approach brings as close as possible together the correlation between the test results and probability of accidents for motor vehicles being apt to lose the driving stability to the different extent.

Thus, the non-conformity referred to in the introduction to the ISO Standard 7401 concerning the lack of the correlation between the test results and the possibility to avoid accident is eliminated to a great extent.

As examples of such road tests recommended by ISO and carried out without driver on board, the following can be mentioned:

- steady state circular test;
- "step-input";
- "sinusoidal input"; etc.

Those tests can mainly be used in case of comparative selection of characteristics of tyres, steering, suspension stiffness and other kinds of works carried out at the development phase and putting motor vehicles into production.

As compared with the abovementioned ISO methods, proposed document with standard requirements allows to solve more wide task of comprehensive assessment of the driving stability and could be accepted as a basis for working out the standardization documents covering other motor vehicle categories including articulated vehicles.

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<table>
<thead>
<tr>
<th>Motor vehicle</th>
<th>Mass, kg</th>
<th>Value of $V_{lim.}$, S = 24 m</th>
<th>$R = 35$ m</th>
<th>$h$, m</th>
<th>$Q_s$ = —</th>
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</thead>
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<tr>
<td>Scout P</td>
<td>2300</td>
<td>91.0</td>
<td>67.0</td>
<td>0.580</td>
<td>1.25</td>
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<td>Nissan Patrol</td>
<td>2320</td>
<td>91.5</td>
<td>67.0</td>
<td>0.593</td>
<td>1.18</td>
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<td>Jeep CJ-7</td>
<td>1880</td>
<td>91.0</td>
<td>66.5</td>
<td>0.573</td>
<td>1.13</td>
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<td>VAZ - 2121</td>
<td>1540</td>
<td>—</td>
<td>—</td>
<td>0.66</td>
<td>1.08</td>
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<tr>
<td>UAZ - 3170</td>
<td>2170</td>
<td>91</td>
<td>70</td>
<td>0.66</td>
<td>1.13</td>
</tr>
<tr>
<td>Martorelli</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LUAZ - 1302</td>
<td>1370</td>
<td>87</td>
<td>69</td>
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<td>0.97</td>
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<tr>
<td>Suzuki - 410</td>
<td>1280</td>
<td>85</td>
<td>62.5</td>
<td>0.597</td>
<td>1.02</td>
</tr>
</tbody>
</table>
Vehicle Design for Secondary Safety

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Vehicle Design For Secondary Safety

Abstract of paper submitted to Road Safety in Europe conference 1992

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This paper provides an overview of the problems, proposed solutions and direction for future research concerning the design of vehicles for secondary safety. Vehicle safety research and development in Europe has grown in a piecemeal manner. Decisions have been made based on national priorities and on the perceived ease of identifying solutions. This piecemeal approach does not lend itself readily to a coordinated research programme that meets the needs of the European Community as a whole. It also makes the identification of related problems that concern different road users more difficult.

This paper addresses the issues that are current across a range of different road users. It establishes the state of knowledge and identifies the major outstanding problems of each group. It then provides a direction for future action whether it be research, development or regulation.

Car occupants are the largest single group of road casualties in Europe and their protection probably consumes the largest portion of most vehicle safety research budgets. The paper discusses issues including the merits of crashworthiness rating scales, the value of airbags compared to other safety measures, current priorities in occupant protection in frontal and side collisions and in rollovers. The need for a deeper understanding of the mechanisms of head and legs injuries are highlighted. The special problems affecting the protection of children in cars are addressed. The particular problems of compatibility between cars and other vehicles are discussed.

Collisions with cars are the most common cause of pedestrian injuries and in some EC countries they form 35% of the fatalities. The paper examines the potential that car design can have to reduce pedestrian injuries and identifies the need for greater implementation of these measures. Many injured pedestrians are children or are elderly and this places special requirements on vehicle design.

Motor cyclists have a relatively high fatality rate although this may vary between countries. The options for their protection are discussed and the issue of leg protection addressed. Changes in the mandatory requirements for helmet performance are discussed together with the implications for countries that already have more demanding requirements. The remaining problems that might feasibly be addressed by design solutions are identified.

The paper briefly discusses injuries sustained by occupants of goods vehicles and of buses and coaches. It compares the hazards experienced by the occupants with those of other road users. The incompatibility between vehicles of radically sizes is assessed and attention is drawn to the value of load retention systems for crashes.
VEHICLE DESIGN FOR SECONDARY SAFETY

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1. INTRODUCTION

Each year 50,000 people are killed on the roads in Europe, equivalent to the population of a small town, at the 1990 UK cost per casualty of £665,000 this represents a cost to the European community of £33,250,000,000 per year. Surviving casualties add to this sum. The reduction in these numbers is seen as a priority and research is being conducted into the most appropriate means to achieve this.

Figure 1: Most Common Road User Fatalities in the European Community 1989

Figure 1 shows the types of fatal road user in the twelve EC countries in 1989. Car users form 51% of all road user deaths and are the largest group of casualties in each country in the EC. The relative frequency of the remaining road user fatalities varies between countries. For example the figure shows that typically 20% of fatalities are pedestrians but this rises to over 30% in the UK and Ireland. Similarly 15% of EC fatalities are riders of two-wheeled motor vehicles (TWMV) but this drops to 7% in Luxembourg and rises to 28% in Portugal. The national priorities within the EC will therefore vary.

There are no statistics available that describe the numbers of surviving road user casualties in a uniform manner, some countries collect them as a matter of course, eg the UK and Germany, others do not. The full scale of road user injuries in the EC is therefore unknown.

Research addresses vehicle safety in two ways, it investigates means to reduce the numbers of accidents occurring and it searches for means to mitigate the severities of injuries when a crash occurs. This paper seeks to describe the progress towards the development and implementation of injury reduction measures known as secondary safety. It addresses the problems concerning the three largest groups of casualties - car occupants, pedestrians and motorcycle riders.
2. CAR DESIGN

The secondary safety design of cars offers the largest potential for fatality and injury reduction of all road user categories and the level of understanding of car occupant protection is the most developed. The introduction of secondary safety performance requirements in the early 1970's places some current development at the level of fine tuning however there are still areas where large scale savings in human life can be made. Early priority was rightly given to the reduction of fatalities but the importance of the survivors has increased with the recognition that many crashes may be unsurvivable while the number of casualties with long term impairment may be large.

The early EC Directives and ECE Regulations dealt primarily with frontal crash protection since they constitute the largest group of impacts at 53%°. The most common striking object is a second car, however when fatalities alone are considered the involvement of trucks and buses doubles to 20%. Over 30% of all fatalities are the result of a collision with a rigid or very heavy object.

Figure 2: Objects Striking Cars, all Impact Directions, all Injury Severities

2.1. Front Crash Protection

The current levels of frontal crash protection built into cars include a limit of intrusion in a front barrier test 4 where a car travelling at 50 km/h strikes a rigid barrier with full overlap. Other regulations require occupant ride-down from the steering system 21° and from the seat belt 6. Front seat belt use is generally believed to be high in much of Europe reaching 95% in some countries 7 so many car designers are routinely able to use the longitudinal members in the front structures to provide additional ride-down. The validity of the front barrier test is now being heavily criticised since the test conditions are in fact rare in real-world crashes°; it also fails to require the improved levels of energy management that are routinely available and it does not assess the levels of injury that occupants might sustain. It is an easy performance requirement for manufacturers to achieve.

2.1.1. Partial Overlap Tests

Real-world car to car crashes most commonly involve a partial overlap of the car front 11. This configuration results in most of the crash loads passing through one of the side members and there is often sufficient energy remaining to cause deformation of the vehicle interior and reduction of the opportunity for occupant ride-down 12 13. Crash data analysis suggests that this intrusion is
often associated with serious injuries which may be life threatening or may cause long term impairment \(^{14, 15}\).

The development of an improved test is centring around the mitigation of the partial overlap condition \(^{18}\). Many groups are examining the 40\% or 50\% overlap crash \(^{17, 18}\) into a block although a 30\(^\circ\) barrier has been suggested as an alternative. Some groups are also using a deformable barrier face to simulate the characteristics of car to car crashes more accurately \(^{19}\). A dummy is used to measure Head Injury Criterion, chest and pelvis acceleration and femur loads which reflect human tolerance to injury. A test that reproduces the conditions where current vehicles sustain steering wheel facia and footwell intrusion and assesses the occupant loads will lead to substantial reductions in fatal and serious injuries.

Tests that simulate the car to car crash may not address collisions with rigid and heavy objects such as trees, lamp posts, trucks and buses. These crashes often have the characteristic of applying the impact loads to a localised area of the car structure - underrun with a truck or a collision with a cast iron lamp post. The energy management in this type of crash is much more difficult and some manufacturers are suggesting that even with full belt use the potential for fatality reduction is limited \(^{20}\). It is likely that for the foreseeable future many of these crashes may be unsurvivable without changes to the roadside environment or truck. Recent studies have concluded that up to 30\% of fatalities resulting from underrun with a truck front could be prevented by the use of lower bumpers or other front underrun protection on trucks \(^{21}\).

2.1.2. Vehicle Aggressivity

It is likely that a partial overlap test requirement will eventually be implemented and that car structures will become optimised for the new condition. A natural step will be for the longitudinal members at the car front to become stiffer as they have to absorb more energy. This may be particularly important for small cars where crush space is more limited. These cars will have the potential to present a greater hazard when in collision with unmodified cars or with the side of other cars and cause the struck vehicle to absorb more energy with consequent intrusion. Many of the cars in current production that are designed for a partial overlap condition are large prestige models \(^{22}\), they often have a relatively high mass which may tend to exacerbate the hazard to occupants of other cars.

In a similar way the use of additional side members at the top of the wings may raise the local stiffness and increase the hazard to pedestrian head and pelvis impact.

It is imperative that the development of an improved frontal crash test be accompanied with an examination of the effects of new designs on the whole accident population. A new test procedure must include a systematic assessment of the aggressivity of vehicles towards other car occupants and pedestrians.

2.1.3. Whole System Test

It has been suggested that one test might be used to examine the level of protection offered by a car, having the advantage of reducing the cost of testing for manufacturers. However it is not possible for a single test to examine the range of conditions apparent in the real-world. For example a dummy might have a head contact with a part of the steering wheel during a crash test but the stiffness and hazard from the steering wheel varies - the rim is generally stiffer at the join with a spoke than in between spokes. The single test will reproduce one steering wheel attitude, one contact on one part of the head, and one head
attitude and velocity. Although this set of conditions might occasionally be the most severe it is not readily controllable and will not be consistent across models of car. Items such as the steering wheel, facia and footwell are better examined more rigorously by the use of supplementary component tests.

In addition a single test will only examine the performance of a car at one speed and several studies have shown that this can lead to systems that give lower protection over the whole range of crash severity 23 24. Techniques are available to optimise crash protection over the full energy spectrum 25.

2.2. Car Downsizing

International interest in environmental issues has focused intensively on the consumption of resources and pollution caused by car manufacture and use. One aspect has been to encourage car manufacturers to build smaller and lighter vehicles to improve fuel efficiency. The mass of a vehicle is a dominant factor in the protection offered - a heavy vehicle will experience a smaller change in velocity than a light vehicle when in collision with another vehicle. The collision between a heavy truck and a car illustrates this mass effect. The introduction in the US of the Corporate Average Fuel Economy standards has had the effect of increasing the rate of reduction of car mass. In one US State the average mass decreased from 1680 Kg (3700 pounds) in 1984 to 1227 Kg (2700 pounds) in 1987. This resulted in an increased injury rate of 14% in car to car crashes, 11% in car to truck collisions and 10% in single vehicle non-rollover crashes 26. Another study based on US fatal accident data states that an increase in driver fatalities is inevitable if any car is replaced by a lighter one or if the whole population of cars is replaced by a new population of lighter but otherwise identical cars 27. The study suggests that fuel economy and safety are intrinsically in conflict. However the changes in the numbers of fatalities resulting from pollution effects and manufacturing processes remains to be estimated.

2.3. Crashworthiness Assessment

The ease with which manufacturers can build cars to supersede the safety levels of ECE Regulation 33 and the lack of information to help consumers choose safe cars has led a number of groups in Europe to develop their own safety rating scales. These employ a variety of methods including staged collisions 28, real-world crash studies 29 and vehicle examination 30. Some combine the appraisal of secondary safety with primary safety effects 31.

Each system has its own advantages and disadvantages.

- Staged collisions can test the performance in severe impacts and dummy readings can indicate the severity of likely injuries but they cannot readily take account of the variety of impact types and human tolerance to injury.

- Inspections rely on the protocol having a clear basis of real-world crash data but, along with staged collisions, have the advantage of being effective at an early stage in the product life cycle. They only address the presence of a feature not its effectiveness but they may take account of potential hazards to other road users. They can also include the inspection of items not subject to legal requirements, for example the face protection offered by the steering wheel. Recent comparisons of the rank order of models inspected and featuring in real-world crashes show a useful degree of consistency 32.

- Feedback from real-world crashes can reflect the full variability of the crash event but requires a large data set before accurate, detailed results are available for a model; they are therefore dependent on the model mix in the population under scrutiny. Analysis of real-world data frequently has the extra problem of insufficient exposure data.
• Examinations of primary and secondary safety effects are particularly
difficult to interpret in the absence of exposure data and are open to
misinterpretation.

The safety rating scales in use in Europe have developed in a piece-meal
fashion. There needs to be a programme to bring together techniques based on
staged front and side collisions supplemented by vehicle inspections to identify
the presence of safety equipment. The results would be published soon after a
car was produced and the results would be supported by later feedback from
crash examinations which would supply more detailed design information. This
programme would keep the advantages of each while avoiding many of the
disadvantages. This type of programme is best operated at a European level to
match the European car market. Unfortunately there is no group that has the
responsibility together with the resources necessary for an undoubtedly
expensive operation.

2.3.1. Occupant Injuries and Contacts

The pattern of injuries sustained by car occupants in frontal crashes varies
depending on the severity of injury and this has a consequent effect on the
ensuing priorities.

When non-fatal severe injuries are examined the legs (43%), chest (27%) and
head (25%) are found to be the most commonly injured. Fatally injured
occupants show a different pattern with injuries to the chest (82%), head (67%)
and abdomen (37%) being more frequent than those to the legs (33%) 33. The
issues for the survivors are therefore concerned with long term impairment,
hospitalisation period and treatment costs particularly resulting from leg injuries.
Those of the fatalities concern the prevention of chest, head and abdomen
injuries to increase the chance of survival.

Seriously injured survivors have on average 1.25 body regions with an injury of
AIS 3 or above while fatalities have an average of 2.58 34. This higher
multiplicity of injury means that a safety measure that reduces severe injuries to
just one body region may not have a large effect on the reduction of fatalities.
For example a fatality may have AIS 5 injuries to the head, chest and abdomen,
preventing the AIS 5 head injury will still leave two other AIS 5 injuries and the
fatal outcome is still likely. On the other hand a measure that prevents an AIS 3
leg injury of a survivor is likely to have a substantial benefit since the casualty is
not likely to have another injury of the same severity.

It is difficult to compare the importance of injuries to the different body regions
of survivors. The normal injury severity scale used is the Abbreviated Injury
Scale 35, this measures the threat to life and therefore can only be useful for
assessing the priorities for fatalities. There is no equivalent scale that assesses
the long term consequences of individual injuries.

Investigations of real-world frontal crashes have identified a set of typical injury-
contact pairs. These include head and face lacerations from glazing materials;
facial bone fractures and minor brain injury from the steering wheel; severe
head injuries from exterior objects; neck sprains following restraint use; chest
bruising from seat-belts; severe thoracic and abdomen injury from the
combination of steering wheel and seatbelt in higher energy crashes; upper and
lower leg fractures from the intruding facia and footwell 36 37 38 39 40.

Current research and development work is addressing a number of these
issues. For example improved belt systems have reduced slack to avoid head
contact with the wheel. Equally there are improved designs of wheel that
minimise facial injury although the supporting test methods have so far failed to
be adopted as a legal requirement. Other problem areas are only partially
addressed - much frontal crash research includes the reduction of femur loads but fails to address the more common and more impairing lower leg and ankle injuries. Airbag development appears solely intended to reduce face injuries while any mitigation of the torso-wheel interaction is incidental. The reduction of head injuries caused by contact with external objects although a difficult task is not being addressed at all.

2.4. Adult Restraint

The effectiveness of seatbelts in reducing injury has been confirmed following the introduction of mandatory use in many countries. A number of improvements to the standard belt have been made including several types of pre-tensioner and their recent use in high volume vehicles is expected to result in reductions of face contacts on the steering wheel and knee contacts on the facia. Other improvements to belt systems have been suggested including the use of an 80g maximum head deceleration, a maximum chest compression of 50 mm and the use of a device to check lap section geometry.

Recently belt effectiveness in protecting car occupants seated on the non-struck side in oblique side collisions has been questioned following estimates that 35% of such occupants come out of the diagonal section. This has been shown to result in head and face injuries from contact with struck side of the car and also belt induced torso injuries.

Future developments in sensor technology may permit the use of intelligent restraints that use crash sensing data, occupant weight and the position of the seat on its runners to tune the restraint performance to the needs of the crash.

2.4.1. Airbags

In the absence of an EC directive mandating a face friendly steering wheel there is much interest in the benefits that might be obtained by the widespread introduction of airbags to the European market. Early US estimates of restraint effectiveness suggested that airbags gave an additional 18±6% effectiveness on top of the 41% effectiveness of lap-diagonal belts when used together. Recent results based on larger accident samples confirm their value as a supplementary restraint but are still insufficient to give detailed feedback on changes to injury patterns.

The so called "Eurobags" intended for European use are generally smaller than the US airbags and typically extend to a diameter slightly larger than that of the wheel. They are intended to mitigate the effects of face contact onto the steering wheel although the reduction in torso injuries is uncertain. Their use as an additional supplementary restraint to seatbelts offers an opportunity to extend frontal crash protection to higher impact severities. The typical price to the consumer is £750, significantly higher than that of the TRL steering wheel. If they are to merit the cost they must be designed to mitigate torso injuries otherwise the face friendly steering wheel is a more cost effective option.

A major shortfall in European legislation is the absence of any Directive mandating performance requirements on airbags. There is no legal requirement for airbags to operate in a manner that will optimally reduce injury, nor are they required to have the capacity to operate after a long interval having experienced a range of climatic conditions. The period before their widespread introduction gives an opportunity to specify appropriate requirements.

The use of airbags in smaller European vehicles raises difficulties less frequently seen in the US market. In particular a smaller car requires a faster trigger and inflator than a large car. Airbag development must also take account of short drivers who sit closer to the steering wheel and may experience higher loads from contact with an inflating airbag.
A further difficulty accompanies the use of passenger side airbags together with rearwards facing child restraints. In such a condition experimental work has revealed that a child can experience very high head accelerations which are double those experienced with no airbag. For this reason the US National Highway Traffic Safety Administration has strongly advised that rearward facing child restraints not be placed in seat positions fitted with airbags.

Prototype airbag systems for side impact have been developed to provide chest ride-down when deployed from an armrest and head protection when deployed from the side header. These novel designs may provide a way of reducing head injuries from contacting exterior objects however there is a need for considerable development before they can be used in production vehicles.

2.5. Child Restraint

2.5.1. Restraint Types

Children have special requirements of car restraint systems. They have a lower tolerance to injury and the strong parts of their bodies are undeveloped and less able to carry crash loads than an adult. Infants particularly have a very different mass distribution with a relatively large head and weak neck muscles. They may not be able to support themselves in an optimum posture. Older children may not wish to stay in one position for a long period.

A number of restraint types have developed to address the needs of each age group. The very youngest children are able to use either carrycot restraints or rearward facing seats. Carrycot restraints normally include an arrangement of webbing straps which encircle the carrycot and secure it in the car. The performance of the straps is specified in regulation. The performance of the carrycot, which applies the loads to the infant, is not specified. Crash tests examining these restraints have shown that the carrycot frequently provides the limiting factor. Carrycots can be designed to carry crash loads but they are frequently not. The use of these restraints may therefore give a completely false impression of security.

A higher degree of protection can be gained from the use of rearward facing infant seats. The child faces towards the rear of the car and the loads in the most common frontal crashes are distributed through the child’s back, there is no concentration of forces along the neck. Real-world studies have shown that this type of restraint can provide a very high level of protection when used correctly. Rearward facing seats are not legal for children above 10 kg in the EC although systems are available in Scandinavia. These are also highly effective in reducing injuries although misuse has been found to be a compromising factor.

Forward facing child seats are frequently used for children between 9 and 36 kg. They may be designed to be solely forward facing or they may also be capable of being used rearward facing by infants. Again they have been found to be highly effective in large numbers of crashes. However there have been a number of accident reports that have shown that cervical spine fractures can occur, these injuries are almost invariably fatal but appear to be confined to children under two years old. They are extremely rare nevertheless an international task force has examined the cases available and come to the conclusion that rearward facing restraints would offer greater protection as would the use of 5- or 6-point harnesses with top tether straps on the seats.

Impact shields are restrained by a lap belt and apply crash loads to the child’s torso, pelvis and thighs. Although there is a risk of ejection to children below 2 years old they can be effective for larger children. They are popular in certain countries and misuse has not been observed to be a problem. They are most
appropriately used for the restraint of larger children and in seats fitted with only a lap belt.

Booster cushions raise the pelvis height of older children and ensure that crash loads are not applied to the soft parts of the abdomen. Again they are very effective in reducing injuries and encouraging seat-belt use.

2.5.2. Child Restraint Misuse

The misuse of child restraints has been identified in as many as 75% of all child restraints and has been observed in many countries. It has been shown experimentally to reduce the levels of protection markedly, a correctly used child restraint reduces fatalities by 70% while partial misuse reduces the risk by only 40%.

Misuse takes many forms. The restraint can be incorrect for the age of the child. A rearwards facing design might be used forwards facing. The restraint can be incorrectly strapped into the car or the may be inadequately secured into the restraint. The harness webbing and any adult belt may be loose introducing excess slack and hence increasing the chance of injury.

The need for the assessment of potential misuse and its likely effects on protection has led to the development of the Misuse Mode and Effects Analysis however the techniques are not sufficiently well accepted to be incorporated into regulation. Several groups have recommended that restraints should only be capable of being installed in one way while new designs incorporate systems allowing harness adjustment with a single strap. A number of manufacturers are now recognising that typically 58% of rear seat occupants are children and are integrating child restraints into the rear seats of cars. Current designs feature booster cushions alone but prototype infant restraint have also been developed.

An installation system called ISOFIX has been developed in Sweden that may avoid some of the difficulties over the installation of the restraint into the car. It also has the potential to deactivate an airbag when one is fitted.

2.5.3. Child Restraint Development

There are a number of opportunities for improving the performance of current child restraint systems. One third of restrained children who are seriously injured are involved in side collisions and prototypes have been built to reduce the injury potential. Rearward facing designs for children up to 2 years old would cover an age range where the risk of neck injury is believed to be still high. The use of top tether straps can reduce forward movement reducing the potential for head contact. Restraints should be designed so as to be capable of being used in one way only while instructions can be written more clearly to minimise misuse. Car manufacturers should routinely fit adjustable belts suitable for the use by older children.

2.6. Side Impact

The reduction of injuries in side collisions has been one of the major areas of secondary safety activity for at least the last ten years. There is now a proposed ECE Regulation describing a test using a mobile barrier and a special side impact dummy. The test aims to reproduce the essential characteristics of a car-to-car side collision and reduce head, torso and pelvis injuries. The design of the barrier has remained largely unchanged since its description in 1985, the intervening time has been spent gaining its general acceptance. The dummy has been more difficult to develop but the current design of the Eurosid dummy has recently gained the approval of ISO as being sufficiently bio-fidelic. An EC Directive requiring side impact protection is likely to be issued in 1996.
probably coming into effect with cars built after 1999. The most recent delays have resulted from the manufacturers wish to have the option of a computerised testing procedure as an alternative to full scale testing. Unfortunately computer simulation techniques are not yet sufficiently advanced and the side impact proposals have been retarded while these techniques are developed.

In contrast the US felt able to issue an Advanced Notice of Proposed Rulemaking in 1988 \(^8\), the Rule was issued as an amendment to FMVSS 214 in 1990 and applies to cars sold after 1995. NHTSA has however recently issued an that may result in Eurosid and Biosid being used as alternatives to its own side impact dummy Sid.

This contrast between the European and US approach to safety regulation raises questions over the effectiveness of the European decision making process and the co-ordination of the technical development of European standards.

The proposals for a side impact requirement simulate a perpendicular car to car collision with an approach speed of 50 Km/h. Comparisons with real-world crashes suggest that the test reflects the essential characteristics of a small proportion of fatal crashes although it simulates non-fatal crashes better\(^7\). In particular 40% of all fatal side collisions are with trees or poles which can result in a different loading to the car side to that caused by cars. Also the change of velocity of fatal real-world crashes is typically much higher than that seen in the test. Finally 29% of all fatalities in side collisions are seated on the non-struck side and they sustain fatal head injuries from striking the intruding side structures in very high energy collisions. It is unlikely that any of the proposed test requirements will result in much improvement for them.

The implementation of the side impact requirements will be a major piece of European secondary safety regulation as it addresses a crash configuration that is particularly difficult to design solutions for. This difficulty has resulted in a number of design strategies, some address the profile of the intruding door face \(^7\) while others deal with the reduction of intrusion \(^2\). As production cars comply with side impact protection requirements it will become essential to monitor the changes so as to facilitate identification of the most effective techniques. A “before and after” study will be of particular value in evaluating the effectiveness of the current proposals and to identify the directions for further progress.

3. PEDESTRIANS

The 1990s continues to see a significant proportion of pedestrian fatalities on European roads. Although the proportions of child and young adult pedestrian fatalities has decreased somewhat over the last decade, longevity has increased and there has been an increase in the number of elderly people being killed on the roads \(^3\).

There are approximately 10,000 pedestrians are killed each year in Europe. Accident data show that around 60% were struck by the fronts of cars. Worldwide research has demonstrated that improved car design can reduce the frequency and severity of these pedestrian accidents \(^4\) and a programme of collaborative research to develop test methods that evaluate pedestrian protection has been undertaken by a European consortium under the auspices of the European Experimental Vehicles Committee \(^5\). This working group has drawn up proposals in the form of a draft regulation.
3.1. Car-To-Pedestrian Kinematics

For the 60% of fatal/serious pedestrian accidents involving the fronts of cars research has shown that the typical trajectory is for the pedestrian to be hit on the side of the body, projected onto the bonnet of the car and then thrown forwards onto the ground as the car slowed down. The most commonly injured body parts affected were the legs though contact with the bumper; the pelvis, abdomen and thighs with the leading edge of the bonnet and wings; and the head with the top surface of the bonnet and wings, scuttle, windscreen/frame or the ground.

80% of all injuries and 25% of fatal injuries are sustained at speeds of 40 km/h or less. Real world accidents studies show that approximately 40% of leg injuries and brain injuries of AIS 3+ occur at these speeds and that improved car design can be effective in mitigating such injuries. The remainder of this section briefly summarises the proposals of the EEVC Working Group.

3.2. Test Methods

The proposed regulations are closely based on European pedestrian casualty data. They include 3 sub-system tests to assess car-to-pedestrian protection. These test methods separately assessed the bumper, the bonnet leading edge and the bonnet top. In all three methods the test velocity was 40 km/h.

3.2.1. Lower Leg Protection

Evaluation of accident data showed that adults, particularly the elderly, were more at risk than children to AIS 3+ leg injuries at impact speeds up to 40 km/h resulting from contact with the car bumper. The car bumper is normally at the level of the adult leg. The bones of the aged are more brittle and fracture more readily and heal at a much slower rate than those of children or younger adults. This sub-system test therefore simulates a bumper striking the adult lower leg.

3.2.2. Thigh/Pelvis/Abdomen Protection

The leading edge of the bonnet is most frequently involved in injuries to the femur and pelvis of adults and the pelvis, abdomen and femur of children. Evaluation of European accident data showed that for accidents up to 40 km/h, injuries of AIS 3+ were more frequently sustained by adults than children. Child abdominal injuries of AIS 3+ was rarely seen at speeds of 40 km/h or less. Therefore, the proposal for this sub-system test is to use an impactor representing a segment of an adult femur.

Many accident studies have shown that children are more resilient than older adults to lower extremity injuries and therefore the use of adult injury tolerance levels will benefit all age groups.

It is considered that the introduction of the Bumper and Bonnet Leading Edge Tests based on an impact speed of 40 km/h would have the potential to reduce the severity of up to 40% of the pelvic or leg injuries of AIS 3 severity.

3.2.3. Head Protection

The head is the most frequent site of life-threatening injuries in all age groups of pedestrian accidents. Accident data showed that around one third of all brain trauma and skull fractures occurred from accidents at speeds below 40 km/h and approximately half of these were sustained from contacts with the fronts of
cars. Adult heads most frequently contacted the most rearward part of the
bonnet top and the wings, the windscreen frame and windscreen; whilst child
head impacts were most frequently associated with contact to the front part of
the bonnet top. The proposals for pedestrian head protection requirements
include the use of an adult head form to assess the rear of the bonnet, wings
and scuttle, and a child headform impactor to evaluate the forward section of
the bonnet and wings.

Accident data show that head impacts to the more rearward areas of the bonnet
are associated with high impact speeds and these are difficult to mitigate
through car design. However, the introduction of both adult and child head form
tests to the bonnet top can reduce skull fractures and brain injuries by up to
25%, provided all cars comply with the test requirements. It is also considered
that improved protection for pedestrians' heads may be possible at higher
speeds.

3.3. Implications For Car/Component Manufacturers

In order to meet these three sub-system test requirements, manufacturers
would need to make the following design changes.

- Deep plastic bumpers mounted from non-protruding mounting points to
  meet the Bumper Test.

- Headlight surrounds in some cars will need attention to comply with the
  proposed test for the Bonnet Leading Edge.

- Reduced stiffness of the top of the bonnet outer shell will be required to
  conform with the head impact tests for the Bonnet Top.

- Adequate free space under the bonnet in relation to the engine components
  would also be required to meet the Bonnet Top test. The most significant
  changes in car design relate to this improvement and some cars may
  require under bonnet re-packaging.

Many cars will already comply with the requirements of the bumper and the
bonnet leading edge as a result of the need for aerodynamic efficiency. It is
therefore already difficult to identify the changes in injury patterns which will
result from the regulation. It will still be important to monitor the effectiveness of
the regulation when it is implemented so as to identify the effectiveness of
pedestrian head protection and any further need for leg protection.

4. Two Wheel Motorised Vehicles

Accident studies of real-world motorcycle crashes have revealed that the
principle body regions injured depend on the mortality of the riders. The most
common sites of fatal injury were the head (46%) chest (25%) and abdomen
(19%). Survivors most commonly sustained injuries to the legs (42%), arms
(25%) and head (20%). In common with car occupants those fatally injured
typically sustain life threatening injuries to several body regions while survivors
will often sustain only one serious injury. On the basis of these results the areas
of rider protection have been directed towards the prevention of head and leg
injuries.
4.1. Head Protection

The use of helmets has been mandated in most European countries and also in the US. The subsequent repeal of US legislation has provided the opportunity for a number of effectiveness studies which have demonstrated the substantial benefits of helmet use. In Europe ECE Regulation 22 specifies helmet performance and includes tests of impact absorption and shell penetration and a dynamic chin strap retention test. There is no examination of impacts to the face or chin guard and the performance requirements take no account of head injury from rotational forces. The absence of these latter requirements has been criticised following crash analysis that showed only 57% of helmet impacts occurred within the tested area. 25% of the impacts occur to the chin-guard and can result in fractures to the base of the skull and also mandible.

The level of protection of helmets sold in the UK is defined by the British Standard BS 6658, this addresses some of the deficiencies of ECE 22 by including the use of an oblique shock absorption test to examine rotational forces, a central impact on the chin guard and a chin strap slippage test. The harmonisation of European safety standards to promote trade after 1992 seems likely to require that ECE 22 be the helmet standard in all EC countries. Unless ECE 22 is improved or the UK is able to abstain from this requirement the level of protection available to UK helmet users is likely to decrease.

There is disagreement between studies over the potential of future improvements to helmet design. Some authors state that the protective capacity of helmet design seems to have been reached with the exception of face protection while others suggest the use of more appropriate injury criteria may give benefits as might improvements in the energy absorption capacity.

4.2. Leg Protection

The legs are the most common site of injury amongst surviving riders and the nature of the injuries is such that the fractures may be accompanied by tissue loss and contamination. Each of these may affect the management of the injuries and the degree of long term impairment. Leg fractures sustained in single vehicle crashes are predominantly to the lower leg, foot and ankle while multi-vehicle crashes result in a greater number of more severe fractures to the lower leg, knee and thigh. Fractures occurring in multi-vehicle crashes are almost invariably a result of rider leg contact with the striking vehicle.

Several groups have developed systems intended to reduce leg injuries, a common feature is the combination of a stiff supporting structure to preserve leg space together with a deformable element to permit a controlled leg ride-down. Most recently this has resulted in a draft specification for the performance of leg protection device. Leg protectors built to this specification are claimed to reduce leg injury while not increasing injuries to other body regions and installations on machines of varying size have been tested. The UK Draft Specification has been heavily criticised by the motorcycle industry which states that it increases leg injuries and modifies the rider trajectory to increase head injuries. A large testing programme accompanies this latter view which contradicts the UK test results. There are however many fundamental differences in test methodology which concern the dummy leg, instrumentation, injury indices, impact angles and approach speeds. The construction of the leg protectors and the vehicles used for the test also introduce differences. Many of these differences are a result of different interpretations of the real-world crash data that underlies the test configurations.

It is obviously important to motorcycle users that these differences be reconciled and to this effect the work has been adopted by ISO/TC 22/ SC 22.
This group has the objective of developing an agreed test procedure that can be used to assess the performance of leg protectors.

### 4.3. Rider Kinematics

The trajectory of a rider is dependant on the interaction with the striking object and one effect of leg protectors is claimed to be a greater degree of pivoting around the knee with a greater severity of head contact with the upper structures of the car. The installation of an airbag has been examined as a means of controlling this trajectory. The devices so far tested have been those intended for use in cars but they still have the capacity to prevent the angulation around the knees. Although these systems are at an early stage in development it is likely that their effectiveness could be improved by the use of airbags tailored for the motorcycle environment. The limited research available does suggest that the combination of leg protectors with airbags has the potential to reduce leg injuries while not causing injuries to other body regions. The challenge has to be the design of devices at a price and style that makes them acceptable to the young age group that are most likely to be involved in crashes as motorcycle riders.

There is an deficiency of crash research examining the causes and nature of injuries to real-world motorcycle users and it is apparent that this has contributed to the difficulty of developing appropriate safety systems. Only one group based in Hannover appears to be conducting studies over a sufficiently prolonged period to monitor changes in injury patterns following a change in design. In particular any widespread sale of ECE 22 helmets in the UK needs to be closely monitored for any increase in injury and fatality. There is a need for a more accurate understanding of the causes of injury and the interaction between the rider and the striking object. Some of this data may not be available from field studies but the verification of test methods and the appraisal of any subsequent safety systems depends on a strong body of real-world accident studies.

### 5. European Accident Data Sources

The introduction of European Whole Vehicle Type Approval in 1994 will serve to strengthen the European car market. Decisions over vehicle design and safety performance have been made at a European level since the 1970s. This centralised activity has not been supported by an equivalent system that evaluates the problems of secondary safety in European vehicles. If any accident research is done at all it is usually financed by individual governments or manufacturers. While it may reflect the needs of the funding group it may not be accepted by other EC countries.

There is a lack of co-ordinated basic information on road user casualties. For example surviving casualties are not counted in a uniform way in the twelve countries, European restraint and helmet use rates are unknown. There is also no representative data describing the patterns and causes of European road user injuries. This makes the assessment of safety priorities difficult to establish and there is no way in which the introduction of safety countermeasures can be monitored across Europe.

There is a corresponding lack of data concerning the causes of accidents and the role of vehicle design, this is referred to in more detail in a companion paper presented at this conference.

The introduction of side impact and partial overlap protection to cars, pedestrian protection and TWMV leg protection systems are all major safety items. There
is currently no way that the effect on the complete European accident population can be adequately assessed.

This lack of a uniform European accident data set has served to delay or prevent many pieces of safety regulation. Frequently the lack of real-world accident data is taken to infer that no problem exists while in reality there is no data because there is no group that collects the data. Examples are the inordinate time taken to implement side impact countermeasures and the inability to agree on the need for a face friendly steering wheel.

In contrast the US has a accident data system that matches with the needs of the safety targets of the NHTSA. The US has a General Estimates System (GES) \(^{101}\) which uses a sample of around 46,000 accidents each year from 60 sites. These crashes represent the estimated 6,500,000 accidents nationally and supply basic data on roadway, vehicle and road user characteristics. This data is supplemented by a greater level of detail collected for all fatal crashes within the Fatal Accidents Reporting System (FARS) \(^{102}\) and a highly detailed data set collected within the National Accident Sampling System \(^{103}\) which collects data on 7000 light passenger vehicles each year.

The centralised consistent approach of the US accident data collection system has facilitated the early development of more demanding safety requirements and a safer vehicle population.

6. SUMMARY

6.1. Car Occupant Protection

- The frontal barrier test requirements need to be replaced by a test addressing partial overlap and including an instrumented dummy to reduce head, torso and leg injuries. The aggressivity of such vehicles to other road users needs to be systematically assessed.
- The reduction in car mass for reasons of fuel economy will result in an increase in car occupant injuries.
- There is a need to bring together the variety of consumer crashworthiness systems to avoid the disadvantages that they each have.
- For the use of airbags in European vehicles to be justified they must be designed to reduce life-threatening torso injuries. There are cheaper ways to prevent facial injuries.
- The use of carrycot restraints without adequate specification of the carrycot performance should be prohibited.
- Restraints must be designed to have a low potential for misuse, this potential must be evaluated as part of the approval process.
- The introduction of the proposed side impact requirements must be accompanied by an assessment of its effectiveness.

6.2. Pedestrian Protection

- The proposals for pedestrian protection appear to have little criticism, they must be implemented quickly together with a system to assess the benefits in real-world accidents.

6.3. Motorcyclist Protection

- The helmet performance requirement ECE 22 has a number of inadequacies which result in its failure to offer the maximum level of protection possible. The UK faces a potentially significant reduction in rider
head protection unless the shortcomings of ECE 22 are resolved or the UK is able to continue to require its higher existing requirements.

- There must be an active approach to the development of systems to reduce leg injuries leading to their introduction to the market. The substantial disagreement between the UK and the motorcycle industry must be resolved.

6.4. European Accident Data Collection

- There is a major deficiency in both basic and detailed accident information concerning road user injuries. This makes the setting of priorities, the monitoring of new and existing standards and the identification of the need for further research highly problematic.

- Europe needs a uniform accident statistics system that supplies accurate estimates of the numbers of casualties of different road user types, their injury severities, the circumstances that led to their injury and the role of the vehicle and other protective equipment.

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Vehicle Design for Primary Safety

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ABSTRACT

There are many initiatives in Europe at present which address the application of advanced technology in vehicles, in particular in cars. The RACE, DRIVE and PROMETHEUS programmes in particular are concerned with the opportunities for introducing advanced electronics and communication systems into cars and the road infrastructure. These initiatives are primarily technology led and are making considerable technological advances in, for example, route guidance systems, collision avoidance systems, driver monitoring systems and so on. Furthermore work on advanced control technology, with special reference to the requirements of disabled drivers (drivers with special needs), is opening up opportunities to dramatically alter the driver/control configuration.

This paper will review the opportunities for the application of advanced technology in vehicles, with particular reference to the implications for the driver and the driving task. The paper will go on to argue that although the technological advances are laudible, they must be effectively implemented in vehicles, taking account of the requirements of the drivers, their effect on the driving task, and on primary safety in particular. The potential for positively influencing primary safety will be examined and the essential human factors work needed to achieve this potential will be discussed. Reference will also be made to the more futuristic considerations of the effect of entirely novel vehicle control systems on occupant injury reduction.
VEHICLE DESIGN FOR PRIMARY SAFETY
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1. INTRODUCTION

The key element in design for primary safety until recently has been the vehicle itself. Much fruitful effort has been channelled towards the improvement of the performance of vehicle braking systems, tyres, suspension systems and so on. A new element has now appeared in the equation, namely in-vehicle information systems or road transport informatics (RTI) systems. These devices provide an interface between the driver, the vehicle and the road traffic system and have immense potential to improve primary safety. There are a number of initiatives in Europe and the USA that address the application of RTI systems in vehicles, in particular in cars. The DRIVE and PROMETHEUS programmes in Europe and the Intelligent Vehicle Highway initiatives in the USA, in particular, are concerned with the opportunities for introducing advanced electronics and communication systems into cars and the road infrastructure. These initiatives are primarily technology led and are making considerable advances in, for example, route guidance systems, collision avoidance systems, driver monitoring systems and so on.

The opportunities that the application of RTI systems in vehicles provide for improving the efficiency and safety of the road traffic system and reducing the number and severity of accidents, must be balanced with positive benefits for the driver and the driving task. Although the technological advances are laudable, they must be effectively implemented in vehicles, taking account of the requirements of the drivers, the effect on the driving task and on primary safety in particular. There is great potential for positively influencing primary safety but the essential human factors work needed to achieve this potential has not yet been completed.

This paper argues that there is a need for more account to be taken of human factors in the development of advanced technology applications in vehicles and that there is a need for an analysis of their effects on primary safety through the investigation of road accidents.

2. KEY ELEMENTS OF PRIMARY SAFETY

If one takes a systems approach to the concept of primary safety, then the four critical components are the man (the driver) - the machine (the vehicle) - the interface (the advanced technology system) and the (road traffic) environment.
The machine - Over the last few decades the advance in technological achievement applied to the primary safety aspects of vehicles has been immense. For example, anti-lock braking (ABS) systems are now commonly available to optimise the braking efficiency of the vehicle. Traction control can reduce the likelihood of spinning during acceleration on slippery surfaces and active suspension control systems can adjust the suspension to minimise vehicle roll during fast turns (Parviainen J.A. (1990)).

The environment - Advances in the use of technology applied in the road traffic environment and applied to the design of the road traffic environment have also had a considerable impact on primary safety. For example, the DRIVE project V1016 INFOSAFE is designing a system to assist the operator in a traffic control centre (Jepsen M. & Kallstrom L. (1992)), and the recently commenced DRIVE project V2005 VRU-TOO is concerned with the reduction of risk and minimisation of delay to vulnerable road users, namely pedestrians.


But what of the fourth essential component in the system, the interface between the man, the machine and the environment?

The interface - In recent years, the application of advanced technology to the driving task has provided new and exciting opportunities to influence and change the way in which the driver interacts with the vehicle and the traffic environment (Parviainen J.A. et al (1988)). The key elements in the success of these systems are how well they interface to the user, i.e. how well they correspond to the actual requirements of the driver and the driving task, and how well they take account of the characteristics and capabilities of the driver - the human factors.

It is argued that only by taking a systems approach in which all the components of the system are addressed, including the human factors, will effective, usable and safe RTI systems be designed and the effect on primary safety be positive (Galer M.D. (1984)).
3. THE ROLE OF RTI SYSTEMS IN PRIMARY SAFETY

3.1 Types of RTI systems in vehicles

When considering the effects on primary safety, the application of RTI systems in vehicles can be considered as falling into the following types:

- **Systems that directly impinge on the driving task**
  There are a number of devices under development or available on the market that have a direct impact on the tasks that the driver performs as an essential part of driving. They can inform the driver of status conditions, suggest appropriate action or take action in place of the driver.

  Collision/obstacle avoidance devices and gap warning devices monitor the presence of objects in relation to the vehicle, such as other vehicles or the edge of the road. They can, variously, inform the driver of the presence/status of the obstacle(s) or make appropriate control actions to avoid the obstacle(s). They can also be applied as (intelligent) manoeuvre control devices for lane change actions. Closely related, from the user's point of view, to obstacle avoidance devices are (intelligent) cruise control devices that maintain a constant speed and/or maintain a constant distance from the vehicle in front.

  Some forms of co-operative driving systems use a combination of intelligent cruise control and intelligent manoeuvring control to enable a number of vehicles, sometimes referred to as a convoy or platoon, to travel together.

  Vision enhancement devices provide the driver with an improved or enhanced image of the road scene when visibility is impaired by adverse weather or lighting conditions.

- **Systems that provide information relevant to the components of the driving environment, the vehicle and the driver**
  There are a variety of devices under development or on the market that provide the driver with information or advice that is relevant to the activities of driving but which are not an integral part of the driving task.

  Driving environment monitoring can take the form of information about weather conditions such as ice, snow and fog. It can also provide information about the road traffic conditions such as intersection hazard warnings that include traffic signal status, planned movement on a crossing route, etc. and traffic congestion warnings that provide indications of hold-ups on the proposed route due to roadworks, accidents, incidents and so on. (Dynamic) route navigation systems provide the driver with explicit information about the manoeuvres necessary to undertake a journey and arrive at a destination.

  Vehicle condition monitoring has been an integral part of in-vehicle information systems (dashboards) since the early days of speedometers and tachometers, oil, fuel and water level gauges. The number of vehicle parameters that it is now possible to monitor and display to the driver have
greatly increased in recent years and include ride level monitors, brake wear, washer fluid level, door and boot closure status, tyre pressure and so on.

Driver condition monitoring devices aim to provide the driver with information for the maintenance of adequate performance levels. They monitor parameters that indicate the detrimental effects of alcohol, medications, tiredness/sleepiness and cognitive overload and underload. The parameters monitored are related to the driver or to driving behaviour.

- Systems that influence the efficiency of the driving task
  Road and route information systems enable the driver to plan his or her route most efficiently, taking into account the types of roads on the journey; the preferences of the planner for, for example, shortest or most scenic routes; routes that avoid certain classes of road or traffic conditions; and routes that take account of real time congestion information.

  Trip computers provide the driver with information related to the journey in which he or she is engaged such as average speed; time to arrival or time of arrival; distance to arrival; fuel consumption at a particular time, or over the journey; range of the vehicle on the remaining fuel and so on.

  Parking guidance systems provide information about the location and availability of parking spaces.

  Some of these devices are also being used as components of auto-policing systems which record data relating to vehicle and driver behaviour regarding traffic accident and safety issues (the so-called 'black box' recorder systems.)

- Systems that are unrelated to driving.
  (Portable) mobile data terminals and office products such as mobile fax machines provide the driver or passenger with information that is unrelated to the primary task of driving. These systems are installed by, for example, the utility companies for use by their maintenance engineers or by commercial organisations for use by their sales force.

  In-car telephones are now widely used by the general public and business people for both social and business purposes.

  These types are not strictly mutually exclusive but they provide a framework within which to consider the characteristics of the applications and the potential effects on primary safety.

3.2 Primary safety issues

The extent to which the various types of system have implications for primary safety depend on the closeness of the links between the technology, the driver and the driving task. The DRIVE Safety Task Force (1991) identifies three levels of safety problem associated with the introduction of advanced information technology in vehicles. These are:
• **System safety.** These systems must be considered as safety critical systems of a most complex sort and the consequences of a design fault or system malfunction in the road environment, the vehicle or both must be taken into account.

• **Traffic safety.** This involves all components of the traffic system working together and should consider the appropriateness of the system to the problem it is designed to treat and the response by the road users to the system.

The Task Force notes that behavioural responses by road users can have unanticipated side effects for systems thought to have no safety implications. An example cited is the Berlin route guidance system trials in which drivers were found to make more trips and to unfamiliar parts of the city. This increased the probability of an accident due to increased exposure to the road traffic environment. Anticipated safety benefits can be partially or completely negated by changes in road user behaviour. Experience based on cars with ABS braking systems indicated that drivers drove faster and closer to other vehicles, thus reducing or negating the potential reduction in accident risk.

• **The man-machine interface design and system usability.** If the man-machine interface is poorly designed drivers may fail to understand or perceive the information; the information may not match the current requirements of the driving task or may differ from the driver's expectations of the system. In addition, attentional demands may lead to mental overload, stress or distraction from the primary task of safe control of the vehicle.

This leads us back to the earlier statements that in order to develop and design easy to use, acceptable and safe advanced technology devices, a systems approach which takes into account the man, the machine, the interface and the environment is essential.

3.3 **Types of accidents which could be addressed by RTI systems**

The DRIVE project V1062 Multilayered Safety Objectives (1992) has analysed the traffic accident statistics from certain European countries and the most serious (i.e. costly) were analysed using a behavioural interaction frame of reference. The RTI applications that may decrease the number and severity of accidents in a given category and the system effects of these measures are considered.

• **Single vehicle accidents on motorways.** The main problems that could be addressed by RTI solutions were identified as drowsiness/falling asleep and inappropriate speed choice in potentially critical situations. They suggest devices that monitor driver status and proper vehicle operation, with warning or intervention when needed. They also suggest that recommending or enforcing proper speed selection at exit and entrance locations might reduce single vehicle accidents at these points.

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• **Rear end accidents on motorways.** The main problems in this case were identified as short headways and inappropriate speeds, often in reduced visibility. They recommend the longer term solution as change of driving style but also indicate that the short term effect of collision avoidance systems is warning or intervening when the danger of collision is imminent.

• **Single vehicle accidents on rural roads.** The main problem was identified as inappropriate speed selection in terms of the road, weather or surface conditions. They recommend devices that warn of sub-optimal conditions or recommending/enforcing appropriate speed limits. Automatic intervention could also be provided if the system perceives improper operation of the vehicle.

• **Head-on collisions on rural roads.** The main problems were identified as incorrect overtaking decisions often combined with excessive speed of the oncoming vehicles and incorrect speed and lane choice on bends. They suggest that systems that prevent excessive speeds both enhance the predictability of the speed of on-coming vehicles and reduce the frequency of overtaking. Both appropriate speed choice and prevention of cutting the corners, they feel, can be promoted by the application of advanced technology solutions.

• **Crossing collisions on rural roads.** The main problems that could be addressed were identified as incorrect speed and gap selection when entering a priority road and the non-homogeneous speed on the major road. They feel that enforcement of correct speed selection at intersections might be the most important measure.

• **Crossing collisions at urban intersections.** The main problem was identified as the need for direct interaction with several partners in complex situations. They consider that a system that intervenes at the level of actual actions or operations is in most cases inadequate in urban traffic. The recommendation or enforcement of appropriate speed could ensure that there is sufficient time for the necessary perception-communication-action.

• **Pedestrian and bicyclist accidents in urban areas,** according to their figures, comprise by far the highest percentage of accidents in the urban environment. The suggested RTI solutions are intelligent traffic signals that detect pedestrians and cyclists, and speed reduction devices for the motor vehicles at critical places. They also make the very salient point that the safety of these vulnerable road users should not be impaired by the introduction of advanced technology devices that are used in urban traffic to promote car mobility.
4. THE POTENTIAL FOR POSITIVELY INFLUENCING PRIMARY SAFETY

A review of the accident information presented above indicates that certain key safety issues can be addressed by RTI systems. These are inappropriate speed; inappropriate headway; drivers low arousal condition; poor overtaking decisions and poor gap selection decisions. Inappropriate speed for the traffic, weather and decision making conditions is the most frequently cited. There are, however, other aspects to the implementation of RTI systems that can have an impact on primary safety (IVHS (1992)). These include reduced exposure to hazardous traffic and driving conditions; less stress for the driver resulting from, for example, traffic congestion; less distraction from the driving task while searching for navigation information and less dangerous recovery from navigation errors; information provided about the impairment of the driver or the vehicle; better preparedness of the driver for the task of driving as a result using planning aids and better accommodation of individual differences between drivers such as age, driving experience and so on. At the same time there is great potential for driver distraction and information overload. Safety improvements in one area must not be to the detriment of safety in other aspects.

The design and implementation of RTI systems, where they can affect the driving task and primary safety will make the difference between a positive and a negative effect on safety. The potential benefits to be gained from the application of the different types of RTI systems and the key issues to be addressed are reviewed below.

• Systems that directly impinge on the driving task
These systems such as collision/obstacle avoidance and gap warning devices, intelligent cruise control, intelligent manoeuvring control and vision enhancement are the ones that directly affect the problems of inappropriate speed and poor gap selection decisions identified in the DRIVE project V1062 mentioned above. All the devices will improve the driving performance of older drivers whose information processing and decision making capacity may be reduced compared with younger drivers. They will also assist the novice drivers who are not sufficiently experienced in such decision making skills. This will help to reduce the variability in skills, abilities and behaviour in the driving population. Vision enhancement devices will also help to reduce the stress drivers experience while driving under adverse weather or lighting conditions where visibility is impaired. There is also a secondary safety advantage to be gained from the effective implementation of speed reduction devices in that the speed of impact in an accident may be reduced. This will affect the energy of the impact and hence the severity of the injuries to the people involved.

Questions to be addressed during design and implementation of the systems include:

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Will the device inform the driver of status conditions (as a speedometer does at present); suggest appropriate action (such as speed reduction); or will it override the driver and automatically take appropriate action?

What are the likely consequences for the driver and other road users of each of these options? Will the driver take notice of status information? Will the driver obey instructional information? Will he or she become dependent on an automatic action type of device and change driving behaviour? Will the driver be lulled into a false sense of security and safety by the presence of the device?

What are the consequences for the vehicle occupants and other road users if the safety critical system fails?

What are the consequences of misuse of such safety critical systems?

- **Systems that provide information relevant to the components of the driving environment, the vehicle and the driver**

These systems that include the provision of information on weather and traffic conditions; route guidance; the condition of the vehicle; and the condition of the driver also have a bearing on the key safety issues mentioned above. Information on weather conditions may influence drivers' speed and overtaking decisions. Information on the condition of the driver may have some effect on drivers' decisions and behaviour. In a similar manner information on the vehicle condition may also have an effect. Traffic information about congestion or other hazards gives the driver the opportunity to alter the route and hence decrease exposure to traffic hazard and congestion. Less time is lost by avoiding traffic congestion and taking more efficient routes, which can lead to less frustration, reduced stress and risk taking. Route guidance systems can help to reduce distraction while searching for road based navigation information and may have the added benefit of less dangerous recovery from navigation errors. These systems are also likely significantly to affect the quality and homogeneity of driving behaviour because they have the potential to accommodate individual differences in drivers such as age, driving experience and physical handicaps. The majority of the devices are information systems. In one way or another they provide the driver with information on which to base judgements concerning the driving task.

Questions to be addressed during design and implementation include:

- Will the device simply inform the driver of status conditions or suggest appropriate action?

- What are the likely consequences for the driver and other road users of these options? Will the driver take notice of status information? Will the driver obey instructional information?
What is the likelihood of the driver becoming overloaded with information or being unable to make correct decisions on the basis of the information presented? Such systems may overcome the problem of drivers under arousal but may not necessarily lead to a safety benefit!

- Systems that influence the efficiency of the driving task

These systems provide the driver with information to enable him or her to interact more efficiently in the road environment by providing route planning or trip information, parking guidance and so on. It is not essential that the information is presented at critical times during the driving task and in some cases it is not necessary that the vehicle is in motion. One benefit to the driver is a decrease in traffic hazard and congestion exposure. In addition, less time would be lost by avoiding traffic congestion and taking more efficient routes leading to less frustration, reduced stress and risk taking. The driver is likely to be better prepared for the driving task as a result of aids in planning and hence better able to make decisions and less likely to be stressed. Upon request, information can be provided about emergency services and places for fuel, food, toilets, rest areas and shopping; hence less uncertainty and stress. These planning systems also enable drivers of different characteristics and abilities to better meet their travel requirements, hence accommodating individual differences in drivers related to age, experience and physical handicaps. This leads to a greater compatibility and homogeneity in the driving environment. These systems also have indirect effects on the driver's levels of arousal and stress. For example, if an information system is well designed it could reduce the stress associated with route finding and hence facilitate decision making. A poorly designed system could have the opposite effect.

Questions to be addressed during design and implementation include:

- Will the device inform the driver of status conditions or suggest appropriate action?
- What are the likely consequences for the driver and other road users of these options? Does it matter whether the information is used or not?
- What is the likelihood of the driver becoming overloaded with information or being unable to make correct decisions on the basis of the information presented?
- When should the information be presented? Should the operation of the device be linked to vehicle condition, i.e. only usable when the vehicle is stationary?
• **Systems that are unrelated to driving.**
These systems include data terminals and telephones that provide the user with information that may be more valuable to them than any described above. In that sense it means that the introduction of such devices into the vehicle may well cause a conflict of interest between the user as worker and the user as driver.

Questions to be addressed during design and implementation include:

- What type of information presentation is appropriate for these kinds of devices, visual or auditory?
- How and when will the driver call up and control the device?
- What is the likelihood of the driver becoming overloaded with information or being unable to make correct driving decisions?
- How likely is it that the driver's attention will be diverted from the primary task of driving to pay attention to the device?
- Should the device be operable while the vehicle is in motion?

**Device independent safety issues**
Regardless of the nature of the device under development there are certain key issues that are common to the design of all devices and which have a critical effect on primary safety. They include:

- The design of the device and the user's interaction with it must accommodate a wide range of drivers' abilities and limitations.
- The locus of control between the vehicle, device and driver must be very carefully considered, not only in terms of the acceptability of the device but also in terms of safety.
- The content of the information the driver needs, whether environmentally initiated or self initiated, to make each function effective; the priorities the driver has for the information; and the effects of redundancy of the information if from more than one source, must be taken into account.
- The interactions between individual devices fitted to the same vehicle and the effect on the driver is a major concern. Very little is known about the optimal modes of interaction between drivers and several devices. There is also a lack of harmonisation between display and control modes. Standardisation across manufacturers would enhance learnability and usability and reduce errors.
The effect of the interaction between vehicles fitted with different devices for the same or a related function must be taken into account.

The interaction between vehicles fitted with the devices and other road vehicles and users must be considered.

The type of information presentation should be appropriate for the device, e.g. auditory warning noise or speech, visual symbolic or graphical display or instructional text. Information format and density should be appropriate for the device. The timing of the information presentation, whether in or out of the vehicle, when the vehicle is moving or stationary will have a significant effect on the design and the safety of the device.

How and when the driver calls up and/or controls the device is crucial for safe interaction, e.g. voice activation, touch screen, hard keys, soft keys, cursor control and so on.

The driver's attention must not be diverted from the primary task of driving in order to pay undue attention to the device.

The consequences for the vehicle occupants and other road users of system failure must be carefully considered.

The consequences of poor design or misuse of such systems can be very hard to anticipate in advance of user trials and even then may not become apparent until the prototypes have been in use for some time.

The introduction of such devices may have an effect on driver behaviour that may not necessarily lead to increased safety. Risk compensation must be considered. Also the effects of improvements in component driving functions may affect each other and possibly isolate the driver from important sensory cues thus affecting risk perception and potentially compromising safety.

At present it is rare for novice drivers to be trained in the safe use of their in-car entertainment systems. How much more critical is it that drivers are thoroughly trained in the safe use of the advanced technology devices discussed in this paper?

These factors have a significant influence on ease of use, acceptability and safety. What is more, the issues to be addressed and the solutions may be different for different kinds of systems. It cannot be assumed that a solution that is appropriate for one type of system will be suitable for another.

The challenge facing the automotive technology industry now, is how to incorporate human factors effectively into the development and design of advanced technology systems so that they deliver the potential benefits to the users without the potential safety costs.
The challenges for the human factors practitioners are twofold. The first is to considerably enhance our understanding of the issues critical to the safe and effective use of advanced technology systems in the automotive application and to undertake research to provide solutions. The second is to present this knowledge to the variety of other people involved in the design and development process in a way that is understandable and useful (Galer M.D. (1985), Simmonds G.R.W. & Galer M.D. (1984), Parkes A. & Howey K. (1991)).

5. A CO-ORDINATED EUROPEAN ACCIDENT STUDY

The effects of advanced technology in vehicles on primary and secondary safety must be studied in detail in order for the current generation of devices to be properly evaluated and for the next generation of devices to be real improvements. At present there are few data available about the effects of these advanced technology systems on the frequency or severity of accidents. There is a strong need for a European procedure for systematically collecting and analysing information, in a co-ordinated fashion, on the causes of accidents and the effects on injury in accidents. Two approaches have been made in the DRIVE programme to address the issue of accident involvement. The first is to develop an on-board system for monitoring and recording aspects of vehicle status during accidents, DRIVE project V1050 DRACO (1992). Accident reconstruction is achieved as an off-vehicle activity. The primary data are vehicle acceleration on a three co-ordinate system together with yaw. Secondary data covers vehicle speed and the operation of a number of on-board control systems such as main lighting, direction indicator circuits and the braking system. There are, however, important socio-political implications including driver acceptance and possible infringement of personal liberty. The project concluded that accident reconstruction is feasible to an acceptable level of accuracy using data from the three orthogonal axes of acceleration and yaw and that it should offer an improvement on current methods. This project is being developed further in DRIVE 2 in the SAMOVAR project (DRIVE 1992). This does not, however, directly address the potential involvement of advanced technology devices in the causes of the accident.

The emphasis in the DRIVE project V10422 ITHACA In-depth Accident Data Collection and Analysis (1992) was on the human factors in the pre-crash phase of an accident, because this is when the RTI systems would have their main effects. The project concluded that the existing official accident statistics are of very limited value for studying the role of human factors and for testing hypotheses concerning safety effects of new information systems in vehicles. They recommend that in-depth accident data collection should be performed because it offers opportunities for detailed descriptions of accidents and a more complete and reliable recording of human factor variables than official statistics. They go on to make the significant point that the mere gathering of detailed data about accidents, without the guidance of a theory or set of hypotheses, is of limited value. Nor can hypotheses
concerning the factors contributing to road accidents be tested empirically merely by gathering accident data. They propose that in-depth studies of accidents should be redefined as case-control studies. This means that corresponding data on exposure should be gathered in addition to data on accidents. This will allow differences between road users who become involved in road accidents and those who do not to be detected. The gathering of data should rely on a descriptive model of road user behaviour and should concentrate on human factors variables whose relationship to accident occurrence has not been well documented in previous research. The human factors variables studied should be relevant to the operation of advanced technology systems in cars.

In terms of secondary safety studies on the causes of injury to occupants in car accidents, there has been little attention paid so far to the possibility of injury resulting from occupant contact with an RTI system. An informal analysis of the ICE Accident Research Unit (Mackay G.M. et al (1985)) database on the causes of injury to occupants in car accidents from non-standard equipment indicates, as one would expect, very few potential cases of injury. There are two main reasons for this, firstly non-standard fitments are often removed from vehicles before the accident investigators arrive and the second is the very small number of devices in vehicles at present. The secondary safety issues studied should also include the potential effects of the reduction of the speed of impacts and potential changes in the types of impacts experienced. Will, for example, the introduction of intelligent cruise control and collision avoidance devices reduce the frequency of frontal impacts? As frontal impacts are those which vehicles are best designed to withstand will there be an adverse effect on occupant protection?

These are all issues that a co-ordinated accident data collection system should address.

6. CONCLUSIONS

- There is a need to take human factors into account when designing and implementing advanced technology systems in vehicles in order for the potential primary safety benefits to be achieved.

- There is a need for a co-ordinated accident data collection and analysis system to provide essential information for the design of safe, future advanced technology devices.
7. REFERENCES


On the Effectiveness of an Active Steering Wheel in Critical Driving Situations
A Proving Ground Experiment

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ON THE EFFECTIVENESS OF AN ACTIVE STEERING WHEEL IN CRITICAL DRIVING SITUATIONS.

- A PROVING GROUND EXPERIMENT -

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According to the terminology of automatic control theory, a control device can be described as 'active' by use of a device which is equipped with an energy source, unlike 'passive control' which does not have any special energy source in the control device. At the guidance and control level of car driving, the steering wheel as an active control device can be used to transmit relevant, additional proprioceptive-tactile (haptic) information cues for lateral control. The installed active steering wheel is employed by way of superimposing or replacing the regular steering torque with artificial torque to indicate critical driving situations to the driver.

This paper reports a proving ground experiment in continuation to earlier studies (Schumann, Färber & Wontorra, 1991; Schumann, Godthelp, Färber & Wontorra, 1991), where the use of an active steering wheel was tested in two critical driving situations which occurred as rare events during the course:

- curve driving,
- dangerous overtaking maneuver.

In the curve driving situation a continuous steering support was compared with a brief, discrete steering wheel warning. To break-up a critical overtaking maneuver a brief vibrating warning cue via the active steering wheel was compared with a brief, acoustic warning cue.

The results are discussed in the context of the control activities (open-loop and closed-loop control) of the driving task and reveal the timing of the different support strategies as a critical variable during manual control.

References:


1 This work was carried out as a part of the DRIVE project V1041 on generic intelligent driver support systems.
ON THE EFFECTIVENESS OF AN ACTIVE STEERING WHEEL IN CRITICAL DRIVING SITUATIONS
- A PROVING GROUND EXPERIMENT -

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1. INTRODUCTION

The present paper discusses the use of an active steering wheel for lateral control at the guidance and control level of the driving task (see e.g. Allen, Lunenfeld & Alexander, 1971).

1.1 Active steering wheel

Each man-machine system consists of two different types of interfaces, the display and the control device. Driving a car, an active steering wheel is not only used as a control device, but also as a proprioceptive-tactile (haptic) display, which is able to convey signals (information cues) in the form of an active movement. Such a control device can be described as “active”, if it is equipped with an energy source, unlike “passive control”, which does not have any special energy source in the control device (see Iguchi, 1988).

Active control devices have been developed mainly for aircraft-control, but there also have been made attempts for automobiles (for a short review see Schumann, Godthelp, Faber & Wontorra, 1991).

In this study the active steering wheel was tested during two driving tasks, which represent two distinguished control activities (see Donges, 1978; McRuer, Allen, Weir & Klein, 1977):

◦ overtaking: mainly open-loop control (after the initiation of the lane change maneuver),
◦ curve driving: mainly closed-loop control (in the curve).

1.2 Research questions

As a continuation of research from simulator studies which showed the use of an active steering wheel under restricted and artificial circumstances (see Färbér, Godthelp, Schumann & Wontorra, 1991), specific research questions concerned the:

◦ proper detection of different, specific proprioceptive-tactile (haptic) signals via the active steering wheel under realistic environmental conditions;
◦ recognition of these signals occurring as “rare events”;
◦ reaction to these signals during different task demand (workload conditions).
2. METHOD: GENERAL ASPECTS

Proving ground area

The experiment was carried out at the BMW test site in Aschheim close to Munich, Germany during November 1991. The schematic course of the test-site is shown in Fig. 2.1. It consists of a two lane road (lane width = 3.75m) with a verge. Driving is only possible in one direction.

![Schematic course of the test-site. Sections with experimental situations are marked.](image)

**Fig. 2.1:** Schematic course of the test-site. Sections with experimental situations are marked.

Instrumented car

The instrumented car used for the experiment is a BMW 730i, which is equipped with a heading control system (see Fig. 2.2). This system is able to assist the driver in the stabilisation of the heading direction by providing proprioceptive-tactile (haptic) information cues via the steering wheel depending on the vehicle's lateral deviation from an "optimal" course (see Bastuck, Naab, Walther & Wertheimer, 1989).

![Description of the heading control system for active steering support in the instrumented car.](image)

**Fig. 2.2:** Description of the heading control system for active steering support in the instrumented car.

The heading control system is based on video image processing for measurement of the vehicle's
lateral deviation. Therefore, the vehicle is provided with a black and white CCD camera with a resolution of 604 x 576 pixels, which records the road in front of the vehicle. A digital image processing unit determines the position of the road markings and measures the lateral deviation. By means of state estimation and Kalman filtering techniques, the lateral dynamical state of vehicle and road (i.e., side slip angle, yaw rate, heading angle, lateral deviation, lateral velocity and road curvature) is calculated as well as possible lateral disturbances (e.g., side wind). From this information artificial twisting forces with different characteristics required in the experiment can be generated on the steering wheel. For this purpose a DC torque motor (80 W, max. torque = 11 Nm) is attached to the steering column. Sensors for vehicle speed, steering wheel torque and angle (0.35° resolution) are also available. Image processing and the subsequent computation of the control algorithms for torque generation as well as the data recording are done by a PC-AT 386, 25 MHz, which is equipped with an image digitizer and analog-digital interfaces.

Subjects

16 male subjects (Ss) participated in the experiment. All Ss had their driving license for at least four years with a driving experience of more than 10000 km per year. Age varied between 22 and 26 years. All subjects had no previous driving experience at the test-site. They were paid for participating in the experiment.

Experimental conditions and design

Ss drove through the course with a predetermined speed five times, which completely lasted about 30 minutes. There were also other drivers on the course testing vehicle handling characteristics. In addition, two other cars needed for the overtaking maneuver drove on the course.

Ss were asked to keep a fixed speed in different sections of the course (see Fig. 2.1):
- 80 km/h on straight_1 (section A),
- 80 km/h in curve_1 (section B),
- up to 120 km/h on straight_2 (section C),
- 100 km/h in curve_2 (section D),
- 80 km/h in curve_3 (section E).

During the complete test-drive steering support was activated and data were recorded for two driving tasks according the following plan:
- round_1: steering support in curve_1 (section B) and curve_2 (section D),
- round_3 or 5: steering support during straight_1 (section A) to interrupt overtaking,
- round_5: steering support in curve_1 (section B) and curve_2 (section D).

In round_2 data were recorded in curve_1 (section B) and curve_2 (section D) under regular steering conditions (baseline). In round_3 or 5 during straight_1 (section A) an acoustic signal was presented to the driver to interrupt overtaking (baseline). Independent variables were varied according to a balanced mixed factor design.

At the start of the experiment each subject was picked up with the instrumented car at a meeting place about 10 km away from the test-site. Two experimenters were in the car; one as a co-driver to inform the subject about the regular handling of the car, and one in the back to control the experiment. After a short introduction by the experimenters about the experiment and the car handling, Ss drove the instrumented car in regular traffic for about 30 minutes to get acquainted with it. The active steering system was activated for short periods to demonstrate the different experimental conditions. After the driver reached the proving ground area the experimenter informed him about the structure of the course, the recommended speed for the different sections, and unique features of driving conditions (no oncoming traffic, possible high speed tests of other drivers on the course). After the experiment Ss had to answer a questionnaire about their assessment of the active steering system. Altogether, the experiment lasted about 75 minutes.
3. DRIVING TASK: CURVE DRIVING

3.1 Method

Task and stimuli

The driver should pass the curves with a recommended speed. He was asked not to cut a corner.

The two experimental curves where data were recorded (section B, and section D, see Fig. 2.1) consisted of each different length, arc, clothoide, and direction. Due to technical reasons only the first part of the curve from section B could be used for data recording. Two light barriers were used for each curve to start and to stop data recording.

There were two groups of task demand:

- **low** task demand: the driver could concentrate on his driving task only. There were no additional interferences (radio off, no conversation with the experimenters);
- **high** task demand: interferences by radio or tape recorder. In addition the driver was distracted by the experimenters by a quasi structured interview. He was asked to:
  - execute all possible control actions in the car (e.g. to operate the radio, tape recorder, heating, light, indicator),
  - talk about his control actions and the comfort of those,
  - explain the dashboard,
  - give possible suggestions for improvement.

Despite these secondary tasks he was advised to concentrate at his driving task.

Two different steering support strategies were used to support the driver during curve driving:

- **discrete warning signal**, implemented at the steering wheel as a directional short (= 0.8 sec) torque shift (amplitude 3 Nm). The signal was activated if the actual lateral position of the car (the left or right fender) was going to touch the boundaries of a virtual safety corridor. The corridor through the curve was calculated according to a normal lateral position (1.90 m; reference: the car's center of gravity) plus a zone of 40 cm to the left and to the right. Steering to much to the right resulted in a torque shift to the left and steering to much to the left in a torque shift to the right, accordingly. To give the driver enough time to react to the warning, the next warning signal via the steering wheel could only be given after two seconds.

![Fig 3.1: Implementation of steering wheel torque characteristic during continuous steering support.](image)

The path error is calculated as the difference of the actual steering wheel angle and the optimal steering wheel angle.

- **continuous support** changing completely the regular steering wheel torque characteristic. The new steering wheel characteristic was calculated depending on the path error through the curve (see Bastuck et al., 1989). As long as the actual course coincided with the calculated optimal
course no torque occurred at the steering wheel resulting in a "force free" steering. Otherwise a redirecting torque indicated in which direction the driver had to correct his steering wheel angle. Steering wheel torque increased up to a maximum of 3 Nm, proportional to the path error (see Fig 3.1).

**Procedure**

Each subject drove the course five times. Since steering support should only occur as a 'rare event' during the test drive, it was only activated - without to inform the driver - in round_1 (section B and section D, respectively) and round_5 (section B and section D, respectively). The order of the use of the two different steering support strategies in the two curves was balanced.

**Data analysis**

For the experimental curves data were recorded with a sample rate of 33 Hz. The following signals were registered:

- \( \delta_s \): steering wheel angle [rad]
- \( \text{latd} \): lateral position [m] (reference point = camera position in the middle of the car, car width = 1.85 m)
- \( v \): vehicle speed [m/s]

After filtering the raw data, the subsequent measures were calculated:

- \( \text{latdsp} \): standard deviation of lateral position
- \( \delta_{qua} \): steering quality (control strategy), operationalized by the sum of directional steering wheel angle changes larger than 0.75 °
- \( V_{\text{mean}} \): mean speed in the curve to the left (section B)
- \( V_{S\text{D}} \): standard deviation of the speed in the curve to the left (section B)

The original design consisted of a three-factor design (steering support strategy, task demand, repetition). However, as the raw data showed, the repetition factor could not be used for data analysis, because for only 9 out of 16 subjects the discrete steering support was activated.

For these 9 subjects a t-test (repeated measures) on differences between means of the two repetition trials (\( \text{latdsp} \) and \( \delta_{qua} \)) was carried out which led to no significant results. Therefore the measures of the two repetition trials of these 9 subjects were averaged and compared to the measures of those subjects where in only one of the two repetition trials the discrete steering support was activated. Now, the data for only one subject could not be used for further analysis (N = 15).

The speed measures could only be analysed for the curve to the left since for the other curve again the discrete steering support was not activated for all subjects.

Differences between steering support strategies were tested by way of an analysis of variance (ANOVA, mixed factor design) which consisted of the following main factors:

- steering support strategies on three levels (discrete steering support, continuous steering support, no steering support);
- task demand on two levels (low vs. high task demand).

**3.2 Results**

Separate analyses of variance (ANOVA, mixed two-factor design) were performed on two dependent variables:

- the lateral control performance, operationalized by the standard deviation (SD) of lateral position,
- the driver's control strategy, reflected by the sum of directional steering wheel angle changes.

For both dependent variables data of two curves for each subject have been analysed.

**Lateral control performance**

The means for the SD of lateral distance are shown in Fig. 3.2. Even though the ANOVA revealed no significant effect for the first main factor steering support strategy \( F(2,26) = 2.1, p = .15 \), an additional
contrast analysis showed significant differences between pairs of means for the comparison discrete steering support vs. no steering support \( t (14) = 2.16, p = .05 \). This shows, that the discrete steering wheel signal has some negative effect on the quality of curve driving.

![SD lateral position for the three steering support strategies.](image)

**Fig. 3.2:** SD lateral position for the three steering support strategies.

Looking at the second main factor, neither task demand was significant \( F (1,13) = .14, p = .71 \), nor the interaction between task demand and steering support strategy \( F (2,26) = .55, p = .58 \). This can be seen in Fig. 3.3.

![SD lateral position for the three steering support strategies and task demand (workload: low vs. high).](image)

**Fig 3.3:** SD lateral position for the three steering support strategies and task demand (workload: low vs. high).

That the high task demand condition did not affect the quality of curve driving can be explained due to the fact that during curve driving the driver could concentrate on his main task and could break up any additionally secondary task.

**Control strategy**

The means of the directional steering wheel angle changes are shown in Fig. 3.4 and 3.5. The ANOVA revealed no significant effects for both main factors - steering support \( F (2,26) = .84, p = .44 \), task demand \( F (1,13) = .16, p = .70 \) - and no significant interaction effects \( F (2,26) = .43, p = .66 \).
The quite low mean of directional steering wheel angle changes is an indication that the two experimental curves seemed to have been rather easy to drive through. Therefore one should have a look at the tendency of the results.

Although not significant, the results are similar to the lateral performance (see Fig. 3.2), with the most steering control actions for the discrete steering support case.

Fig 3.5: Mean of directional steering wheel angle changes for the three steering support strategies and task demand (workload: low vs. high).

Interestingly, the highest differences with regard to the task demand conditions occur for the continuous steering support.

Longitudinal control performance

Since the performance and the quality of lateral control during curve driving is also affected by longitudinal control, an ANOVA has been calculated also on the average speed and the SD of speed in the curve. The reasoning behind this is that the different steering support strategies and the additional information the driver receives via an active steering wheel might influence the driver's longitudinal control performance.

Due to the experimental design and some missing data for one of the two experimental curves, the dependent speed variables could only be analysed for one curve (curve to the left, recommended speed of 80 km/h = 22.22 m/s) with half of the subjects (N=8).

An ANOVA (one factor, within-subjects design) revealed no significant differences for the steering
support strategies on the mean speed \[ F (2,14) = .73, p = .50 \], which is depicted in Fig. 3.6.

![Fig. 3.6: Mean speed for curve 1 for the three steering support strategies (see Fig. 2.1 section B, curve to the left, recommended speed = 22.22 m/s).](image)

However, the ANOVA resulted in significant effects for the SD of speed \[ F (2,14) = 3.69, p = .05 \]. This can be seen in Fig. 3.7.

![Fig. 3.7: SD of speed for curve 1 for the three steering support strategies (see Fig. 2.1 section B, curve to the left, recommended speed = 22.22 m/s).](image)

An additional contrast analysis attributed the differences between pairs of means to the discrete steering support strategy [discrete - continuous: \( t(7) = -2.53, p = .04 \); discrete - no support: \( t(7) = 2.11, p = .07 \)].

Although the mean speed in the curves is the same for all the steering support strategies, the discrete steering support strategy seems to have some impact on the longitudinal control behavior of the driver.

### 3.3 Discussion

Comparisons between steering support vs. regular steering did not lead to many significant results in this study (see the similar results for control strategy, or the identical results for lateral control performance with continuous steering support vs. regular steering, Fig. 3.2). Nevertheless, it would be rash in one's judgment to conclude that an active steering wheel for lateral support would have no effect on driving performance. One major reason might be curves at the proving ground, being probably...
to easy to drive through with respect to curvature and open view. This reservation should be kept in mind for the following discussion.

Comparing the two different steering support strategies reveals significant differences. At this point it should especially be noted that the continuous steering support, which changes completely the steering torque characteristic compared to regular steering, did not affect the quality of curve driving. The decreased quality of curve driving as measured by the lateral control performance in the case of discrete steering support can be explained due to the timing of the warning signals. Curve driving can be described with a two-level model of driver steering behavior (Donges, 1978), acting more in serial order (Godthelp, 1984). This steering behavior consists of anticipatory open-loop control before the curve and in the curve entrance phase, and switches after that to closed-loop control. The steering activity during the closed-loop mode depends on the accuracy of the preceeding anticipatory steering action.

The timing of the discrete warning signal is implemented such, that the discrete steering support strategy establishes a save corridor for the driver, based on lateral distance. Only if the driver reaches the boundary of this corridor a discrete warning is triggered. The warning signal which occurs during the closed-loop control phase can make the driver unsure, since the driver’s steering adjustments are based primarily on visual cues from the heading angle, rather than on cues from the lateral position on the road (e.g. Lee & Young, 1986; McLean & Hoffmann, 1973). The significant high values of SD of speed (see Fig. 3.7) might also be a possible indication to the driver’s uncertainty as one way of compensating his curve driving strategy.

Two options can be derived from this for future experiments:
- a warning time strategy based on the TLC-concept (Godthelp, Milgram & Blaauw, 1984), which takes into account the heading angle as input variable,
- and/or to push forward the warning instant of a discrete signal, as possible to the anticipatory open-loop control phase, which starts as curve negotiation process about 1 sec before the curve entrance (Donges, 1978). Special considerations should be given to develop a more economical strategy for the triggering of that warning signal.

Different task demand (workload) levels did not show any significant effects. Also this result has to be judged carefully, since the driver always had the possibility to concentrate on the main task during curve driving. However, there seems to be a tendency for more steering control actions in the steering support conditions at the higher task demand level (see Fig. 3.5). This can be explained with the relative inexperience of the driver with an active steering wheel. Especially with the continuous steering support, the driver has to get acquainted to the different steering wheel torque compared with the driver’s internal model of regular unsupported steering, and therefore the driver might use a different control strategy.

Keeping in mind the sub-optimal generation of the steering wheel signals due to the technical restrictions of the employed hardware, the results of this experiment after all are promising also from the viewpoint that the use of active steering did not impair the steering control. The possible negative and unintended reaction of the driver towards a warning via an active steering wheel has frequently been an objection against the use of active steering support, especially if it might occur as a “rare event”. This however was clearly not the case in this experiment, which was designed to have the active steering support as “rare events” (as much as this is possible at all in an experimental setting). It showed that an implementation with perceptible, but not too strong signal characteristics can counteract such unwanted driver’s reactions.

Future research therefore should concentrate:
- in a fine tuning of active steering support, especially with regard to a fit of the artificial steering characteristics of the continuous steering support and the internal driver’s model about steering (e.g. a regular steering torque if there is no path error and a perceptible increase of the steering torque in case of larger errors),
- towards a reconsidering of warning time strategy for the discrete steering support signals.
4. DRIVING TASK: OVERTAKING

4.1 Method

Task and stimuli

Before the start of the experiment the subject was instructed that other cars on the course should be overtaken as in everyday traffic. To test proprioceptive-tactile (haptic) warnings for dangerous overtaking maneuvers, two critical overtaking situations were set up by the experimenters during round_3 and round_5 after the following script (Fig. 4.1):

- with start of round_2 car_1 follows the experimental car in a normal distance;
- car_2 is parked on the verge of a straight course section (section A, see Fig. 2.1);
- in round_3, with the subject being 150 m away from the parking car_2, the driver of car_2 gets a sign from the experimenter and starts abruptly to get back into the right lane of the course;
- this maneuver of car_2 forces the subject to start overtaking;
- at the same moment car_1 accelerates and changes to the left lane to overtake the subject's car;
- this causes a critical situation and the subject is warned to break up his overtaking maneuver.

The same procedure is repeated in round_5 with different cars.

![Critical overtaking maneuver with the cars involved (car_1 and car_2 start their maneuvers at time x, the experimental car after a reaction time x+rt)](image)

Again there were two groups of task demand (low and high, see chap. 3.1). Two different warning signals could indicate the driver to break up his overtaking maneuver and to stay in the right lane:

- **an acoustic signal** in form of a short (0.5 sec) tone. For that a little speaker was installed at the side of the driver's headrest;
- **a proprioceptive-tactile (haptic) signal** implemented at the steering wheel as a short (= 0.7 sec vibrating (= 7 Hz) torque shift (amplitude = 1.5 Nm). This steering wheel signal resembled the signal from earlier simulator experiments (Schumann et al., 1991). Due to technical constraints an exact replication of that signal could not be implemented.

A vibrating steering wheel signal was chosen to clearly distinguish that signal from the other discrete steering wheel signal used in the curve driving task.

The warning instant for both signals was triggered by a TLC measure of 0.75 sec, which represents the Time-to-Line-Crossing, i.e. the time remaining until the left fender of the car would cross the center line of the road (see Godthelp et al., 1984).

A simple algorithm for TLC-calculation on a straight road is described in Fig. 4.2.
Fig. 4.2: Description of the TLC-algorithm to trigger the warning signals.

Procedure

Since critical overtaking situations should be "rare events" only two such incidents were set up during the whole five rounds lasting test-drive. The incidents occurred on different locations in section A during round_3 and round_5. The order of the two different warning signals was balanced.

Data analysis

Even though the critical overtaking situation was highly trained with the two drivers of car_1 and car_2, too many subjects did not break up their overtaking maneuver. The reason for that was that the scenario was very time-critical:
- if car_1 was pulling out to the left lane too early, the subject did not start the overtaking maneuver at all, since he noticed the car in the back in time;
- even if a warning was given, the driver was not forced to break up his overtaking maneuver since he still had the chance to speed up and to try to finish the overtaking maneuver. This also happened a lot, either because car_1 was a little bit late or since the subject had the impression that he still would have enough time to finish his maneuver.

Due to the reduced data base the results are presented in a descriptive form.
4.2 Results

In only 21 out of 32 cases, subjects started an overtaking maneuver. A comparison of the reaction to the two different warning signals is presented in Fig. 4.3.

![Fig. 4.3: Reaction to the two different warning signals (vibration at the steering wheel or tone).](image)

The trend shows a more likely reaction to the proprioceptive-tactile (haptic) warning via the steering wheel.

If one compares the reaction to the two different warning signals with regard to the task demand groups, another interesting trend becomes visible (see Fig. 4.4 and Fig. 4.5).

![Fig. 4.4: Reaction to the tone for the two task demand groups.](image)
While task demand seemed not to be a factor to influence the driver's reaction to the vibrating steering wheel signal, there was no driver in the high task demand group who reacted to the tone. This may just be another hint for the low information content of the tone to break up the overtaking maneuver.

4.3 Discussion

Since the experimental situation was very time-critical it has to be kept in mind that the drivers' reaction to break up or to continue overtaking is moderated by his experienced dangerousness of the situation. This especially becomes visible in the drivers' comments to questions why they did not break up the overtaking maneuvers. They mostly argued that they had perceived the warning signal but that they took the freedom for themselves to react after a subjective judgement of the situation.

Nevertheless, looking at the results there seems to be a trend towards a different reaction to the two warning signals. Whereas as reaction to the steering wheel signal four out of ten subjects broke up overtaking, this only happened in one case as reaction to the tone. This subject was in the low task demand group. This seems to support at least the conjecture that an acoustical unspecific signal like the short tone has a very low stimulative nature. Additionally the danger always exists that it will be ignored in cases when the auditory sensory channel of the driver is well load, as it is often the case (e.g. radio, conversation, noise).

Compared with that, the vibration via the steering wheel contains much more specific information and the signal directly intervenes into the control behavior of the driver. This might even be the reason that it is experienced more unpleasant by the driver. On the other hand this intervention seems to cause the driver to break up the overtaking maneuver more likely as the results show, even in the high task demand group (see Fig. 4.3 and 4.5). The complete process can be seen in the context of stimulus-response compatibility (Wickens, 1984) where the receptors of the information in the hand synchronously serve as effectors for the steering reaction, thus allowing faster reaction to the stimuli. It can be argued and shown partly in the results that a steering wheel vibration can be an effective signal to break up an open-loop control behavior, like during the process of overtaking; since the vibration disturbs the peripheral-feedback mechanisms of open-loop control (Sheridan, 1984; Summers, 1989) and therefore causes the driver's attention to the overtaking process.

Further research should concentrate in a fine tuning of such a vibrating signal, a point which could not be accomplished due to technical constraints of the active steering wheel. It could also divert the reservation of some subjects who perceived the steering wheel signal as unclear and jerky.

Additionally, very exact criteria for triggering the signal have to be found including more knowledge about traffic in the back and ahead to prevent false alarms.
ACKNOWLEDGEMENT

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REFERENCES


The Role of Car Size and Aggressivity in Relative Collision Safety

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THE ROLE OF CAR SIZE AND AGGRESSIVITY
IN RELATIVE COLLISION SAFETY

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Abstract

There is concern about car size and safety, particularly the roles of crush aggressivity and size in relative safety. Recent research by BASt (1,2) has shown, when two small cars collide in a frontal accident that the injury risk is twice the risk when two large cars collide. They also show that the mean risk of injury in a small car, regardless of the size of the opposing car, is 2.5 times that of large cars.

This paper treats the frontal crush behaviour of cars as energy absorbers and shows that the Specific Energy Absorption Capacity of the car population can be regarded as being independent of car mass and length.

The implication of the Specific Energy Absorption Capacity of the car population being independent of car size or mass is that the mean collision deceleration is inversely proportional to car length. Taking relative injury risk as proportional to mean deceleration to the 2.5 power (after gadd, HIC) this relationship, \((L_2/L_1)^{2.5}\), is compared with the relative injury risk data for collisions between cars of similar mass and its variation with size obtained by BASt (1,2) and high correlation \((r = 0.9856)\) obtained. The crush model is then extended to impacts between cars of different sizes and is compared first with BASt data for collisions between cars of different masses and high correlation obtained and secondly with Falksam (3) data for the relative safety of 47 individual cars where linear correlation is obtained.

The model is then used to evaluate the influence of the stiffness of car fronts, soft, average, hard and of the variation of car mass within each size class on relative safety.

References

1. Ernst G. et al "Safety in small and large passenger cars": IRCOBI Cong. 1991

2. Ernst G. et al "Compatibility problems of small and large passenger cars in head on collisions: 13th ESV Conf 1991, paper 91-SI-0-12

1. INTRODUCTION

Research both in Europe and the United States has shown that car mass has a profound influence on the risk of occupant injury in car crashes (1 to 9). In the U.S. Evans (6) showed, when two similar cars collided together in a frontal collision that injury risk was inversely related to car mass. Ernst and his colleagues at BASt (1,2) demonstrated that a similar phenomenon pertained in Europe viz. that when two small cars collide frontally together the injury risk is greater than when two heavy cars collide together and that the injury risk to the occupants in two 700 kg. cars is twice the injury risk to the occupants in two 1400 kg. cars which collide together. Evans (8) has also shown that this phenomenon was similar for seat belted and for non seat belted occupants i.e. the change in relative injury risk with car mass was similar for both seat belted and non seat belted occupants. Evans concluded that the effectiveness of seat belts with regard to occupant protection was independent of car size. Consequently some other factor must be responsible for the mass effect. This paper examines the energy absorption characteristics of the car population in frontal collisions and shows that the aggregate specific energy absorption capacity of the car population is independent of car size and that this phenomenon has an important role in the car size effect and relative injury risk.

2. SPECIFIC ENERGY ABSORPTION AND CAR CRUSH

2.1. Theory

The effectiveness of structures in absorbing energy is measured by determining the amount of energy they absorb per unit mass (10). The specific energy absorption of a
structure is related to the normalised crush depth in the following manner,

$$\frac{E}{M_k} = SEAC \times \left( \frac{d}{L} \right)^n$$

where the exponent, $n$, depends on the force deflection characteristics of the structure under consideration and the specific energy absorption capacity, S.E.A.C. is,

$$SEAC = \frac{F_m \times L}{M_k}$$

where $F_m$ is the mean force absorbed by the structure at maximum deflection, $L$ the overall length and $M_k$ the mass of the structure.

Figure 1. Variation in S.E.A.C. with Car Size.
2.2. Car population

Wood (11,12) has shown that when the frontal barrier specific energy absorption data for individual cars are plotted as a function of normalised crush depth (d/L) the characteristics are similar to one another and further that the car population can be represented as having a common, aggregate, relationship. Figure 1 shows the S.E.A.C. values for 16 cars plotted as a function of overall length. The S.E.A.C. values are independent of car size and have a mean of 1206 Joules/kg. with a coefficient of variation of 0.162.

Analysis of data on a further 145 car types from (13) confirms that the specific energy absorption capacity of the car population is independent of car size (11,12,14). The implication of a uniform mean S.E.A.C., independent of car size, is for a given severity of impact, say, for example, a 48 Km/hr barrier impact, that the crush depth is proportional to car length. That this is so, on average, is not surprising when it is considered that other dimensional parameters of cars such as wheelbase, distance to front of engine, are proportional to car length (12).

![Figure 2. Comparison of Theory and Accident Data for Crashes between Similar Cars.](image-url)
3. RELATIVE INJURY RISK MODEL

In accident research, DeltaV, the change in velocity experienced by the vehicle and occupants is used as a measure of accident severity and has been correlated with injury severity. However the injury causing mechanisms more directly relate to the decelerations and deformations experienced by the occupants. Gadd (15) showed, for the range of impact durations involved in car to car or car to fixed object collisions, that injury risk was related to the 2.5 power of mean deceleration. This relationship has been used to measure chest injury risk, the Chest Severity Index, but is now predominantly used as a measure of head and brain injury severity, the Head Injury Criterion (H.I.C.).

In deriving an injury risk model for car to car collisions involving the car population the following assumptions are made,

1. All car sizes experience the same distribution of collision closing speeds.
2. All car sizes and their occupants have similar degrees of occupant protection.
3. The load in each car size, occupants, luggage, etc., is a similar proportion of car mass independent of car size.
4. The pattern of collisions is the same for all car sizes, all have the same proportion of full frontal, 30% overlap, etc., impacts.
5. Each car size has a similar collision involvement with all other car sizes.

3.1. Collisions between similar cars

On the basis that injury risk is proportional to the 2.5 power of mean deceleration it can be shown (12,14) when two similar cars collide with each other that the relative injury risk to the occupants compared with the occupants of the baseline collision pair is,

\[ RIR_{s \rightarrow s} = \left( \frac{SEAC_c}{SEAC_b} \right)^{\frac{15}{6}} \times \left( \frac{L_b}{L_c} \right)^{\frac{5}{2}} \]  

In other words the relative injury risk is inversely related to the 2.5 power of the ratio of the overall length of the car pairs where, b, is the baseline pair and c, represents the collision pair under consideration.
3.2. Collisions between dissimilar cars

When dissimilar cars collide together the relative injury risk relations depend on the manner in which the two cars interact together and on the ratio of the resultant crush depths. Empirical analysis of frontally crashed cars yielded the following relation (14),

$$\frac{d_p}{d_c} = \left(\frac{L_p}{L_c}\right)^{2.342} \times \left(\frac{M_c}{M_p}\times\frac{SEAC_c}{SEAC_p}\right)^{1.342}\quad 4.$$  

When two dissimilar cars collide together the Comparative Injury Risk for the occupants in the case car relative to its collision partner is,

$$CIR_{c \text{ to } p} = \left(\frac{SEAC_c}{SEAC_p} \times \frac{L_p}{L_c}\right)^{1.036} \times \left(\frac{M_p}{M_c}\right)^{1.462}\quad 5.$$  

This relation compares the relative risk of injury between the occupants of the two cars, $M_c$ and $M_p$, with respect to each other.
3.3. Overall injury risk

In real life each car type collides with a wide range of other cars and the aggregate collision performance of each car size or type will depend on the range of car sizes with which it collides. It is hypothesised that the Overall Relative Injury Risk, O.R.I.R., which can be considered as the frontal crashworthiness rating, for any given car size can be derived by assuming that its collision partner has a mass and length equal to the mean mass and length of the car population under consideration. This yields the relation,

\[
OIR = \left( \frac{SEAC_c}{SEAC_{pop}} \right)^{15/8} \times \left( \frac{L_{pop}}{L_c} \right)^{25/4} \times \left[ \left( 1 + \frac{M_c}{M_{pop}} \right) \times \left( 1 + \frac{d_{pop}}{d_c} \right) \right]^{5/8}
\]

where \( L_c \) and \( M_c \) are the length and kerb mass of the case car size under consideration while \( L_{pop} \) and \( M_{pop} \) are the mean length and mass of the car population.

Figure 4. Comparison of Theory and Accident Data for Overall Relative Injury Risk.
4. VALIDATION OF MODEL

In order to compare the real life data with the theoretical model it is necessary to know the interrelationship between car mass and length. Correlations were carried out between car mass and length for 864 saloon cars specified in (16). Both linear regression of length with the cube root of kerb mass and power regression of mass and length yielded high correlations. The relations obtained were,

\[
L = -0.74 + 0.49 \times M_k^{\frac{1}{3}} \tag{7}
\]

\[
L = 0.257 \times M_k^{0.403} \tag{8}
\]

These equations were used to derive car length from kerb mass.

4.1 Collisions between similar cars

BASt(1,2) published data on the variation in the relative risk of serious or fatal injury in frontal crashes between cars of similar size based on the investigation of serious injury or serious material damage accidents in Rhine-Westphalia over the period August, 1984 to December, 1988 where seat belt usage was in excess of 90%.
Evans(6) published data for the proportion of fatal and serious injuries in frontal collisions between cars of similar mass in New York State in 1971 and 1972 and for North Carolina for the period 1968-1972. Evans(7) detailed the variation in relative fatality risk with car size for collisions between cars of similar size for the period 1975 to 1989 obtained from the U.S. Fatal Accident Reporting System, (F.A.R.S.). This particular data is for all collision types, front, side etc.

Figure 2 compares the four sets of real accident data with equation 2. The relative injury risk model and the data show similar trends. A high degree of agreement between the data and calculated Relative Injury Risk values is apparent. Power regression of the form

\[ RIR_{act} = c \times RIR_{calc}^n \]

was carried out to compare the actual and calculated Relative Injury Risk values. The results of the analysis are shown in Table 1.

<table>
<thead>
<tr>
<th>Data Source</th>
<th>N</th>
<th>C</th>
<th>n</th>
<th>r.r</th>
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</thead>
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<td>8</td>
<td>1.012</td>
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<td>0.943</td>
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<td>0.974</td>
<td>0.915</td>
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<td>FARS 1975-1989</td>
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<td>1.044</td>
<td>0.663</td>
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<tr>
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<td>31</td>
<td>0.994</td>
<td>0.985</td>
<td>0.814</td>
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Table 1. Regression of similar car to similar car data with model.

The power regression indicates a virtual 1:1 correspondence between calculated and actual values. There is high correlation between the model and the BASt and the New York plus North Carolina data, all of which is for frontal collisions, both on an individual and combined basis. The model also shows high correlation with the F.A.R.S. data for fatality risk between similar cars irrespective of collision type.

4.2 Collisions between dissimilar cars

Equation 5 indicates that when two dissimilar cars collide together that the Comparative Injury Risk is related to the inverse of the car lengths and masses to the 1.036 power and to the 1.462 power respectively. Figure 3 compares equation
There is a good match between calculated and actual Comparative Injury Risk values except for the two data points at a mass ratio of 2.0 which are lower than predicted indicating that the Comparative Injury Risk in the smaller car was lower and that in the heavier car higher than predicted by equation 5. Power regression shows that,

$$RIR_{act} = 1.04 \times RIR_{calc}^{0.966}$$

with a coefficient of determination of 0.975 for N=20. Note that the model derived in equation 5 indicates that the C.I.R. is proportional to the 1.88 exponent of mass ratio when the correlation between length and mass in equation 8 is used while the BASt data indicates a power relation of 1.75. These compare with an exponent of 3.74 obtained by Evans (8) for all F.A.R.S. frontal crashes for 1975 to 1989 and an exponent of 2.81 for all F.A.R.S. frontal crashes involving cars for model years 1980 to 1989.

Figure 6. Variation of Relative injury Risk with Car Mass and Mass Ratio of Collision Partner.
4.3 Overall Relative Injury Risk

In equation 6 it is hypothesized that the Overall Relative Injury Risk, O.R.I.R., is equivalent to the case car colliding with a collision partner of mass and length equal to the mean mass and length of the car population under consideration. BASt(1,2) detailed the proportion of serious and fatal driver injuries in 10 car mass sizes for 650 to 1550 Kg. Figure 4 compares the BASt data with equation 6. The Overall Relative Injury risk is set to 1.0 for the mean population mass of 1050 kg and mean population length of 4.24 metres. Folksam Insurance (4) published data on the Overall Relative Injury Risk for 47 cars derived from actual accident experience in Sweden. Figure 5 compares the model and the Folksam data. Linear regression of the model, BASt and Folksam data yields the comparison shown in Table 2.

<table>
<thead>
<tr>
<th>Data Source</th>
<th>N</th>
<th>Equation</th>
<th>r.r</th>
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<td>ORIRa = 0.04 + 0.987.0IRc</td>
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<tr>
<td>Folksam</td>
<td>47</td>
<td>ORIRa = 0.10 + 1.020.0IRc</td>
<td>0.615</td>
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Table 2. Comparison of overall injury risk data with model.

Figure 7. Overall Relative injury Risk and Car Size.
The correlation between the actual data and the model prediction is very high particularly for the BASt data which has a virtual 1:1 correspondence. The BASt data is based on the comparison of different car mass sizes, each size range containing numbers of different car types. Consequently the mean Specific Absorption Capacity of each size class can be regarded as corresponding to the overall population mean. By comparison the Folksam data compares the individual performance of specific car types.

5. INFLUENCE OF CAR MASS AND CRUSH ON RELATIVE SAFETY

5.1 Relative Safety and Mass

BASt(1,2) and Evans(6 to 9) have shown that when two cars of similar mass collide together the relative injury risk to the occupants varies inversely with car mass. This means, occupants of two 600 Kg cars will have twice the injury risk of the occupants of two 1200 Kg cars. The relative injury risk model, derived on the basis that the aggregate Specific Energy Absorption Capacity of the car population is independent of car size and that the injury risk is proportional to mean deceleration to the power of 2.5, postulates that relative injury risk is inversely related to the ratio of car lengths to the power of 2.5. Power regression analysis of length and mass data of 864 cars shows that overall length is related to mass to 0.403 power, equation 8. This and the Relative Injury Risk model combine to give the inverse mass relation found by BASt and Evans.

When the colliding cars have dissimilar mass the injury risk in the lighter car increases relative to the similar car collision while the injury risk in the larger car diminishes. Figure 3 shows the Comparative Injury Risk in the small car relative to the larger car. This shows that when the heavier car is 1.5 times the mass of the lighter car the Comparative Injury Risk in the smaller car is 2.15 times that of the occupant in the larger car and when the heavier car is 2.0 times the mass of the lighter car the Comparative Injury Risk in the smaller car is 3.65 times that of the occupant in the larger car.

However by comparison with a collision with a car of similar mass the injury risk for the occupant in each car has changed by a lesser amount, increasing by 18% for the lighter car when the collision partner is 1.5 times its mass and by 30% when the collision partner is 2.0 times the mass of the case car. Figure 6 shows the pattern of Relative Injury Risk with mass of case car for collisions with similar cars and for collisions with collision partners of
different mass ratios. Taking, for example, 800 Kg and 1600 Kg cars alternatively colliding with similar cars and with each other gives the variation in Relative Injury Risk shown in Table 3.

<table>
<thead>
<tr>
<th>Collision Type</th>
<th>800 Kg</th>
<th>1600 Kg</th>
</tr>
</thead>
<tbody>
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<td>Partner of similar mass</td>
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<td>0.655</td>
</tr>
<tr>
<td>800 Kg car with 1600 Kg car</td>
<td>1.70</td>
<td>0.465</td>
</tr>
<tr>
<td>Change in R.I.R.</td>
<td>+30%</td>
<td>-29%</td>
</tr>
</tbody>
</table>

Table 3. Influence of dissimilar car mass on change in Relative Injury Risk for case car occupants.

This data confirms the dominant effect of the mass of the case car in determining the Relative Injury Risk to the car occupants.

5.2 Influence of S.E.A.C. or frontal crush aggressivity

The S.E.A.C. or Specific Energy Absorption Characteristics of the individual car can be regarded as its structural aggressivity, a car with a low S.E.A.C. being considered "Soft" as greater deformation is required to absorb energy but this results in lower decelerations and a car with a higher S.E.A.C. being considered as "Hard". The equations derived for the Relative Injury Risk model show that the S.E.A.C. values have a profound influence on injury risk with injury risk diminishing with decreasing S.E.A.C. values. Analysis of the S.E.A.C. characteristics of individual car types shows that the distribution of mean S.E.A.C. values of individual car types has a coefficient of variation of 0.162. We can examine the influence of aggressivity by taking the "Soft" car as having an S.E.A.C. equal to the 1st Quartile S.E.A.C. value and the "Hard" car as having an S.E.A.C. equal to the 3rd Quartile S.E.A.C. value. For collisions between cars of similar mass the influence of S.E.A.C. on Relative Injury Risk is shown in Table 4.

The effect of a low S.E.A.C., "Soft" value for the case car is to reduce the relative injury risk for its occupants even where its collision partner has an above average S.E.A.C., "Hard" value. The opposite effect occurs when the case car has a "Hard" structure. Based on the quartile values of mean
S.E.A.C. when two "Hard" cars collide their comparative injury risk is 1.46 times that of the occupants of two "Soft" cars which collide together.

<table>
<thead>
<tr>
<th>Case</th>
<th>Car</th>
<th>Collision Partner</th>
<th>Relative Injury Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft</td>
<td>Soft</td>
<td></td>
<td>0.82</td>
</tr>
<tr>
<td>Soft</td>
<td>Hard</td>
<td></td>
<td>0.89</td>
</tr>
<tr>
<td>Average</td>
<td>Average</td>
<td></td>
<td>1.00</td>
</tr>
<tr>
<td>Hard</td>
<td>Soft</td>
<td></td>
<td>1.09</td>
</tr>
<tr>
<td>Hard</td>
<td>Hard</td>
<td></td>
<td>1.20</td>
</tr>
</tbody>
</table>

Table 4. Influence of frontal crush aggressivity on relative Injury Risk to car occupants.

5.3 Overall Relative Injury Risk

The Overall Relative Injury Risk to the occupants of any car depends on the mass of that car relative to the particular car population and on its relative structural energy absorption characteristics. A light car will, in general, collide with heavier cars consequentially its Overall Relative Injury Risk is higher than for collisions with similar cars. The reverse is true for heavier cars which will, in general, collide with lighter cars.

The influence of car mass and degree of structural aggressivity on Overall Relative Injury Risk is shown in Figure 7. This demonstrates that the increased O.R.I.R. of the lighter cars can be partially compensated by the use of a less aggressive "Soft" structure. The line A-A on figure 7 demonstrates the wide range of car masses which have the same O.R.I.R. or crashworthiness rating as a result of frontal crush stiffness variation.

Analysis of the influence of the S.E.A.C. properties of car fronts on Overall Relative Injury Risk is shown in Table 5. The table shows that a light or small car which has a Lower Quartile S.E.A.C. frontal stiffness will have the same O.R.I.R. as a car which is 34% heavier and has an Upper Quartile S.E.A.C. frontal stiffness. The table further shows that a small car with a Lower Decile S.E.A.C. has the same O.R.I.R. as a car which is 75% heavier and has an Upper Decile front stiffness.

Of course if all cars and car sizes used equally "Soft" front structures the comparative O.R.I.R. disadvantage of
the small car would not be improved. However, much more importantly, the absolute injury risk for all cars would be reduced.

<table>
<thead>
<tr>
<th>AGGRESSIVITY of PARTNER CAR</th>
<th>AGGRESSIVITY of CASE CAR</th>
<th>LOWER 2.5%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>1.16</td>
<td>1.32</td>
</tr>
<tr>
<td>Upper Quartile</td>
<td>1.34</td>
<td>1.53</td>
</tr>
<tr>
<td>Upper Decile</td>
<td>1.53</td>
<td>1.75</td>
</tr>
<tr>
<td>Upper 2.5%</td>
<td>1.78</td>
<td>2.03</td>
</tr>
</tbody>
</table>

Table 5. Variation of mass ratio of partner car with aggressivity for equal O.R.I.R. of case and partner cars.

6. DISCUSSION

Analysis of the frontal crush characteristics of the car population shows that the specific energy absorption characteristics of the car population is independent of car size. Fundamental mechanics shows that the consequence of this characteristic is that the mean deceleration experienced by a car during the course of an impact is inversely proportional to the length of the car and that small cars, even when they collide with each other, experience higher decelerations than large cars. Gadd (15) has shown that overall injury risk is related to deceleration to the 2.5 power. Consequently the injury risk in small cars will be greater than in large cars. This theoretical postulation is shown to explain the car mass effect reported by Evans (6), Ernst (1,2), Folksam (4) and others for collisions between similar cars, between dissimilar cars, and the overall injury risk rating of a car size within the car population. Examination of the range of frontal aggressivities of the present car population shows that there is substantial scope available to reduce the risk of injury to car occupants by the use of "Softer", less aggressive, fronts for cars. This approach to car crashworthiness can be used to offset, at least partially, the negative effects of low car mass and size.
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Transport of Dangerous Goods

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Denmark
Suggested paper for the conference

ABSTRACT

Niels O. Jørgensen, Technical University of Denmark.

In a project concerning the transport of dangerous goods - chemicals, oil products etc. - a model has been developed for the estimation of the probability that a given truck will have a serious accident during a trip along a given route in a highway network. Data are taken from the Danish national highway network. Results show that accident density is not a linear function of flow and that truck accidents are not proportional to the percentage of trucks.

The model handles both road sections and intersections. The degree of urbanization is included in order to give some indication of population density along the elements of a chosen route.

A model for the description of the consequences of accidental spilling of certain categories of chemicals on roads is developed in another project.

One application is to select a least risk route for a given shipment from A to B. Another application is to evaluate possible locations of industrial plants from the point of view of minimizing transport risks of the products.

A further step is under way: the development of a similar model for risks associated with rail transport in order to facilitate choice of transport mode from the risk point of view.
Transport of Dangerous Goods
Niels O. Jørgensen
Professor
Institute of Roads, Transport & Town Planning
Technical University of Denmark

A model for highway risk estimation for trucks.

1. Background.

Goods transport has been increasing in recent years and the international market developments tend to support the trend. Goods transport by trucks take a large share of the market, about 2/3 of inland transports in the Nordic countries.

In European countries dangerous goods amount to between 6% and 16% of the total truck transports (OECD 1988). Dangerous goods in inland transports are mainly petroleum products, about 80% in Germany.

In Denmark dangerous goods amount to 6% of all truck transports. Bernhoft et. al. (1990) reports from a Danish study of serious truck accidents that in 6.7% of these the truck was a tanker while 3.4% of the trucks were registered to carry dangerous goods. So trucks carrying dangerous goods seem to take their share of serious truck accidents.

2. Purpose and content of a model.

This paper examines the transport of dangerous goods from a special point of view: Given a truck transport from point A to point B in a highway network where several routes are possible. Which route is the safest?

This apparently narrow formulation may have different applications. One application is the immediate one: Which route should be chosen for a shipment if transport risk is important? Another point of view could be: A new production plant should be located. If the location of the likely customers, e.g. other industries, are known the location of the new plant might be chosen from the point of view of minimizing transport risk.

Future applications could be wider. Given a knowledge of the total transport of dangerous goods in an area the model might tell which locations were likely frequently to be exposed to the risk from dangerous goods. This might lead to the selection of compulsory routes or to the selection of appropriate security measures. Or if a similar model for rail traffic risk could be formulated the model would be able to select both routing and means of transport.
The formulation of a model for the probability of a truck having an accident involving the spilling of dangerous materials contain the following steps:

find the probability of a truck accident happening on a given road network element i.e. an intersection or a road section,

find a method to add up the probabilities along a route of road network elements,

find the probability that a truck involved in an accident will leak out dangerous materials.

3. The basic truck accident model.

This part of the model expresses the number of truck accidents on road network elements. Basically, we want to express the number of truck accidents, TAC, as a function of the road and traffic conditions:

\[ TAC = f(\text{road layout, area type, ADT, \% trucks}) \]

Through many years a model for the number of accidents on road sections has been used in Denmark (Jørgensen 1969) of this type

\[ U = L \cdot a \cdot N^p \]  \hspace{1cm} (1)

where
- \( U \) = number of recorded accidents per year
- \( L \) = length of road section
- \( N \) = average daily traffic ADT (motor vehicles/day)
- \( a \) and \( p \) are regression coefficients

With \( N \) as the independent variable function (1) shows for a given type of road the relationship between \( U \) and \( N \). The constant \( a \) represents the overall level of accidents while \( p \) gives the form of function (1). If \( p = 1 \) the relation is linear, if \( p < 1 \) accidents are less than proportional to traffic, if \( p > 1 \) accidents increase relatively more than traffic. It has turned out that constants \( a \) and \( p \) are specific to the road layout type and to the type of development (business area, housing area rural area etc). The combination of road type and development is referred to as the aptype of the road.

A study of accidents at intersections (Jørgensen et. al. 1983) gave the same type of relationship between accidents and traffic flows:
\[ U = a \cdot N_1^{p_1} \cdot N_2^{p_2} \]  \hspace{1cm} (2)

where

- \( U \) = number of recorded accidents per year
- \( N_1 \) = traffic flow on major road
- \( N_2 \) = traffic flow on minor road
- \( a, p_1, \) and \( p_2 \) are regression coefficients.

For the intersections there is also a classification in ap-types depending on intersection regulation, geometry and development.

Formulas (1) and (2) gives the accidents in general. A model for the number of trucks involved in accidents is found through modifications of these formulas. Official statistical data (police data) on personal injury accidents and material damage accidents is the basis for this paper. Trucks are for this purpose defined as vehicles > 6t. The percentage of these out of the total flow is named %TR.

The modifications have been made this way. Define

- \( U \) = number of recorded accidents per year
- \( \text{Inv} \) = involved parties (cars, trucks, pedestrians)
- \( \text{InvTR} \) = involved trucks per year
- \( \text{TR} \) = truck flow (Trucks per day)
- \( \%\text{TR} \) = \( \frac{\text{TR}}{N} \)%.

The expected number of involved trucks per year on 1 km of road is formally found through formula (3):

\[ \text{InvTR} = U \cdot \frac{\text{InvTR}}{U} \cdot \frac{\text{InvTR}}{\text{Inv}} \]  \hspace{1cm} (3)

The second factor in (3) \( \text{Inv}/U \), involved parties per accident, has been studied. It is fairly stable. For all the different ap-types it varies between 1.5 and 2.0. The tendency is that urban areas and intersections have the higher values probably due to more single vehicle accident in rural areas and on road sections. For each ap-type this fraction is considered constant and equal to the average.

The third factor in (3) \( \text{InvTR}/\text{Inv} \) was expected to depend on percentage of trucks, %TR, and total volume, \( N \). However, data indicated that for a given %TR value this factor does not depend on \( N \) (fig 1). A study of the relationship between \( \text{InvTR}/\text{Inv} \) measured as % and %TR shows that an expression of the type given in (4) is a good approximation (fig 2).
Parameters b and q are fairly similar for groups of ap-types (fig. 2) and are estimated accordingly.

If we introduce (1), (2) and (4) into (3) we find the expected number of involved trucks

on road sections:

\[
\frac{Inv TR \cdot 100}{Inv} = b \cdot (\% TR)^q
\]  \hspace{1cm} (4)

\[Inv TR = a \cdot N \cdot c \cdot b \cdot (\% TR)^q \cdot 10^{-2}
\]  \hspace{1cm} (5)

at intersections:

\[Inv TR = a \cdot N_1 \cdot p \cdot N_2 \cdot p \cdot c \cdot b \cdot (\% TR)^q \cdot 10^{-2}
\]  \hspace{1cm} (6)

In expressions (5) and (6) a, b, c, p, p_1, p_2 and q are constants depending on the ap-type of the road network element.

The probability of a truck being involved in an accident P(TAC) is now estimated as the involved trucks on a road network element over the number of trucks passing that element. We find

on road sections:

\[P(TAC) = \frac{Inv TR}{365 \cdot N \cdot (\% TR) \cdot 10^{-2}}
\]  \hspace{1cm} (7)

at intersections:

\[P(TAC) = \frac{Inv TR}{365 \cdot (N_1 + N_2) \cdot (\% TR) \cdot 10^{-2}}
\]  \hspace{1cm} (8)

Introducing (5) into (7) and (6) into (8) we find

on road sections:

\[P(TAC) = \frac{a \cdot b \cdot c \cdot N^{p-1} \cdot (\% TR)^q}{365 \cdot N^{p-1} \cdot (\% TR)^q}
\]  \hspace{1cm} (9)

at intersections:
4. Accidents relevant to dangerous goods transport.

In order to come closer to accidents relevant to the topic a number of corrections must be put on expressions (9) and (10).

The analysis of Danish accident statistics has been based on a fairly broad truck definition including busses, rescue vehicles etc. A closer examination has given that on the average 63% of these vehicles are actual trucks > 6t. This figure is rather stable over different road types and geographical units, so it is used henceforth. The figure is named $k_2$.

The relevant accidents are those which are potentially serious to the truck. A first estimate of these are arrived at by selecting truck accidents with personal injury where the counterpart is not a pedestrian, a cyclist or a mopedist. These accidents are calculated for the different ap-types giving

- Urban areas 29%
- Rural areas 43%
- Motorways 21%

These factors should be multiplied on expression (5). The factor is named $k_1$.

In order to improve the estimation of potentially serious accidents a sample of the texts on the statistics forms have been read. It contains about 5 lines of clear text. For accidents selected through the procedure leading to factor $k_1$ it appears that probably more than half of them are in reality not serious to the truck. This means that still one factor $k_3$ must be added to expression (5). The statistical files give an estimate of 0.3 - 0.4 but the estimate is quite uncertain so far and a better value would require other methods, possibly the use of insurance data. A first guess could be 0.3.

The first estimate of potentially dangerous truck accidents is therefore expressions (5) or (6) multiplied by the factors $k_1$, $k_2$ and $k_3$.

The complete formulas for the probabilities of a truck having an accident when passing one km of road or one intersection are

**for road sections:**

$$P(TAC) = \frac{a \cdot b \cdot c}{365} \cdot N_1^{p_1} \cdot N_2^{p_2} \cdot (\%TR)^{-1} \cdot (N_1 + N_2)^{-1}$$ (10)
Numerical example:
The different ap-types and the numerical values found from Danish accident statistics (1982 - 1986) are given in Appendix 1.
Consider a 1 km street section, width 7-8 m (ap-type 115) with ADT = 6000 veh/day and 15% trucks. For type 115 we have:

\[ a = 5.43 \times 10^{-3}, \quad b = 3.38, \quad c = 1.81, \quad p = 0.65, \quad q = 0.49 \]

Expression (9) gives \( P = 1.09 \times 10^{-6} \) which means that the statistical expectation is that 1.09 trucks per million trucks passing this 1 km section is involved in an accident. For type 115 we have furthermore:

\[ k_1 = 0.29, \quad k_2 = 0.63 \text{ and } k_3 = 0.3. \]

This gives a probability of \( 6.0 \times 10^{-8} \) that a potentially serious truck accident will happen during a truck passage of that street section.

5. Safest route model.

The road network used for tests is the Danish state highway network. The road network elements - road sections and intersections - are labelled with values for ADT, % trucks and ap-type. Together this defines all relevant parameters in the formulas (11) and (12), see appendix 1.

For each network element the probability of an accident is estimated from (11) multiplied by the element length or from (12). Adding up probabilities over different routes e.g. by means of the Moore algorithm for shortest routes it is possible to find the route having the smallest probability of an accident.

\[ \text{Note:} \]

When the probability of an accident over a route is estimated it should ideally be taken into account that if an accident happens on one network element it could not happen to the same truck on another element on the same trip. Theoretically this is very easy if a Poisson model for the accident occurrence is assumed. Instead of having

\[ \text{Routerisk} = \sum_i P_i \cdot l_i \quad (13) \]

the Poisson assumption will lead to

\[ \text{Routerisk} = 1 - e^{-\sum_i P_i \cdot l_i} \quad (14) \]

Given that the \( p_i \)-values are small the difference between (13) and (14) are small and the ranking of routes will be the same.
6. Discussion.

Accident risk is usually defined through:

\[ \text{Risk} = \text{Probability of acc.} \times \text{consequence of acc.} \]

This paper only deals directly with the probability factor. Indirectly, however, the statistical data contain information on population density through the classification of the area in which the accident has happened. The Danish data contain 7 urbanization categories such as business area, dense apartment area etc until pure rural area. Although the ap-types do not distinguish between all these the information is carried over into the datafile. This allows a guess of the population density which is necessary if the consequence of a given truck accident should be estimated.

A consequence model must first estimate the probability that a truck, given an accident has happened, will release its cargo. This requires knowledge of the truck accident pattern. A study of this is reported by Brockhoff (1992) in a paper to this conference. Different models for the distribution of accident consequences exist. A frequency/consequence risk curve for road and rail transport is reported by OECD (1988). A complete consequence model is needed for a full evaluation of risks associated with different route choices.

One interesting development of this model system would be to extend the model to cover road and rail transport simultaneously. A preliminary study based on Danish railway accident data (Hartelius, 1990) for the years 1970-89 has a few observations. Data include accidents on main line tracks and exclude shunting. Hartelius finds that the overall accident rates are:

- Passenger trains: \(0.54 \times 10^{-7}\) acc./train-km
- Goods trains: \(4.40 \times 10^{-7}\) acc./train-km

The accident rate for goods trains seems to be substantially higher than for passenger trains. If the data are split into derailments and collisions he finds:

- Derailments, pass.: \(0.29 \times 10^{-7}\) acc./train-km
- Collisions, pass.: \(0.25 \times 10^{-7}\) acc./train-km
- Derailments, goods: \(3.27 \times 10^{-7}\) acc./train-km
- Collisions, goods: \(1.13 \times 10^{-7}\) acc./train-km

If the risk using rail transport should be made comparable to road transport then risk differences over the rail network should be known. This would correspond to the risk differences between ap-types in the road network.

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Hartelius tests a few hypotheses in order to explain variation in accident rates between links in the total network. The data are insufficient to give precise answers but there are indications that differences between links might be explained through a model including flow, link length, station density and the number of main line tracks through stations.

A number of detailed studies would have to be made before a joint road-rail network could be considered. Examples are the risks when loading/unloading between truck and train, safety regulations for tanks in goods trains, the frequency of broken tanks at derailments etc.

7. Acknowledgements.

The ideas of this model work have been developed in cooperation with H. Styhr Petersen and Lars Brockhoff of the Technical University of Denmark (TUD) and Palle Haastrup of The EEC Joint Research Center, Ispra. Karsten Hartelius, student at TUD, did the programming work. Stig Hemdorff assisted with access to the road data bank at the Danish Road Data Laboratory.
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Appendix 1
Table of model parameters for different ap-types.

A
Road sections, urban areas

<table>
<thead>
<tr>
<th>Lay out</th>
<th>ap-type</th>
<th>no</th>
<th>a · 10^3</th>
<th>p</th>
<th>b</th>
<th>q</th>
<th>c</th>
<th>k₁</th>
<th>k₂</th>
<th>k₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 lanes</td>
<td>&lt;6 m</td>
<td>113</td>
<td>0,58</td>
<td>0,91</td>
<td>3,38</td>
<td>0,49</td>
<td>1,61</td>
<td>0,29</td>
<td>0,63</td>
<td>0,3</td>
</tr>
<tr>
<td>2 lanes</td>
<td>6-6,9 m</td>
<td>114</td>
<td>2,95</td>
<td>0,70</td>
<td>3,38</td>
<td>0,49</td>
<td>1,76</td>
<td>0,29</td>
<td>0,63</td>
<td>0,3</td>
</tr>
<tr>
<td>2 lanes</td>
<td>7-7,9 m</td>
<td>115</td>
<td>5,43</td>
<td>0,65</td>
<td>3,38</td>
<td>0,49</td>
<td>1,81</td>
<td>0,29</td>
<td>0,63</td>
<td>0,3</td>
</tr>
<tr>
<td>2 lanes</td>
<td>8-8,9 m</td>
<td>116</td>
<td>6,21</td>
<td>0,64</td>
<td>3,38</td>
<td>0,49</td>
<td>1,83</td>
<td>0,29</td>
<td>0,63</td>
<td>0,3</td>
</tr>
<tr>
<td>2 lanes</td>
<td>9 m</td>
<td>117</td>
<td>21,86</td>
<td>0,50</td>
<td>3,38</td>
<td>0,49</td>
<td>1,89</td>
<td>0,29</td>
<td>0,63</td>
<td>0,3</td>
</tr>
<tr>
<td>3 lanes</td>
<td></td>
<td>118</td>
<td>54,85</td>
<td>0,45</td>
<td>3,38</td>
<td>0,49</td>
<td>1,85</td>
<td>0,29</td>
<td>0,63</td>
<td>0,3</td>
</tr>
<tr>
<td>4 lanes (not motorw)</td>
<td>119</td>
<td>18,04</td>
<td>0,54</td>
<td>3,38</td>
<td>0,49</td>
<td>1,90</td>
<td>0,29</td>
<td>0,63</td>
<td>0,3</td>
<td></td>
</tr>
</tbody>
</table>

B
Road sections, rural areas

<table>
<thead>
<tr>
<th>Lay out</th>
<th>Motorway</th>
<th>121</th>
<th>0,17</th>
<th>0,86</th>
<th>2,55</th>
<th>0,70</th>
<th>1,57</th>
<th>0,21</th>
<th>0,63</th>
<th>0,3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limited access road</td>
<td>122</td>
<td>0,16</td>
<td>0,89</td>
<td>3,23</td>
<td>0,62</td>
<td>1,67</td>
<td>0,43</td>
<td>0,63</td>
<td>0,3</td>
<td></td>
</tr>
<tr>
<td>2 lanes</td>
<td>&lt;6 m</td>
<td>123</td>
<td>0,87</td>
<td>0,77</td>
<td>3,23</td>
<td>0,62</td>
<td>1,67</td>
<td>0,43</td>
<td>0,63</td>
<td>0,3</td>
</tr>
<tr>
<td>2 lanes</td>
<td>6-6,9 m</td>
<td>124</td>
<td>0,90</td>
<td>0,75</td>
<td>3,23</td>
<td>0,62</td>
<td>1,63</td>
<td>0,43</td>
<td>0,63</td>
<td>0,3</td>
</tr>
<tr>
<td>2 lanes</td>
<td>7-7,9 m</td>
<td>125</td>
<td>0,29</td>
<td>0,88</td>
<td>3,23</td>
<td>0,62</td>
<td>1,73</td>
<td>0,43</td>
<td>0,63</td>
<td>0,3</td>
</tr>
<tr>
<td>2 lanes</td>
<td>8-8,9 m</td>
<td>126</td>
<td>16,49</td>
<td>0,42</td>
<td>3,23</td>
<td>0,62</td>
<td>1,63</td>
<td>0,43</td>
<td>0,63</td>
<td>0,3</td>
</tr>
<tr>
<td>2 lanes</td>
<td>9 m</td>
<td>127</td>
<td>19,82</td>
<td>0,40</td>
<td>3,23</td>
<td>0,62</td>
<td>1,79</td>
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<td>83,92</td>
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<td>4 lanes (not motorw)</td>
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C
3-arm intersections

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<th>$b$</th>
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<td>0,98</td>
<td>0,36</td>
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<td>0,73</td>
<td>1,89</td>
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<tr>
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<td>137</td>
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<td>0,38</td>
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<td>Urban</td>
<td>138</td>
<td>1,35</td>
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<td>0,32</td>
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<td>0,73</td>
<td>1,89</td>
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D
4-arm intersections

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<th>$k_1$</th>
<th>$k_2$</th>
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<td><strong>Signals</strong></td>
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<tr>
<td>Channelization</td>
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<td>0,63</td>
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<td></td>
<td></td>
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<td></td>
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<tr>
<td>Urban</td>
<td>144</td>
<td>0,08</td>
<td>0,64</td>
<td>0,54</td>
<td>1,89</td>
<td>0,73</td>
<td>1,94</td>
<td>0,29</td>
<td>0,63</td>
</tr>
<tr>
<td><strong>No signals</strong></td>
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<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Urban</td>
<td>146</td>
<td>0,43</td>
<td>0,33</td>
<td>0,66</td>
<td>1,89</td>
<td>0,73</td>
<td>1,94</td>
<td>0,29</td>
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<tr>
<td>Rural</td>
<td>147</td>
<td>15,29</td>
<td>0,08</td>
<td>0,46</td>
<td>2,37</td>
<td>0,66</td>
<td>1,97</td>
<td>0,43</td>
<td>0,63</td>
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<td></td>
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<td></td>
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<tr>
<td>Urban</td>
<td>148</td>
<td>17,90</td>
<td>0,11</td>
<td>0,34</td>
<td>1,89</td>
<td>0,73</td>
<td>1,94</td>
<td>0,29</td>
<td>0,63</td>
</tr>
<tr>
<td>Rural</td>
<td>149</td>
<td>5,36</td>
<td>0,24</td>
<td>0,39</td>
<td>2,37</td>
<td>0,66</td>
<td>1,97</td>
<td>0,43</td>
<td>0,63</td>
</tr>
</tbody>
</table>
Urban road sections

\( \frac{\text{InvTR}}{\text{inv}} \)

\( b = 3.38 \)
\( q = 0.49 \)

Rural intersections

\( \frac{\text{InvTR}}{\text{inv}} \)

\( b = 2.37 \)
\( q = 0.66 \)
Transport of Dangerous Goods
A Risk Management Model

Niels O Jørgensen
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Institute of Roads, Transport and Town Planning
Technical University of Denmark
Denmark

and

Lars Brockhoff
Commission of the European Communities
Joint Research Centre, Ispra
Italy
Traffic Accident Environment of heavy vehicles

L. Brockhoff

Commission of the European Communities
Joint Research Centre, Ispra,
i.p. 321, 21020 Ispra, (VA) - Italy

Abstract

The type of accident in which a tanker transporting dangerous goods is involved (the accident environment) is important for the assessment of the consequences to the tanker. It makes a large difference if the tanker collides with an other truck or merely runs off the road.

The accident environment analysis is based on the 17645 accidents involving heavy vehicles that occurred in Denmark in the period 1983-88. Four major findings are presented:

1. The speed distribution of heavy vehicles involved in accidents. It is shown that the speed distribution for heavy vehicles and for "all vehicles" involved in accidents are similar, although the speed limit for trucks in Denmark is 70 km/h (if not stated lower). It is furthermore observed that the percentage of speeding elements was higher for heavy vehicles, than for other vehicles on average.

2. The fraction of accidents which are collisions is shown to be 69-78% depending on the road type.

3. The distribution of "collision partner" (according to weight). It is shown that 7-12% of collisions involve other heavy vehicles and 68-75% involve automobiles, depending on the road type.

4. An analysis of the distribution of the collision point at the heavy vehicle. It is shown that 40-46% of collisions occur head-on, 31-51% side-on the heavy vehicle and that 10-25% contact the rear-end of the heavy vehicle. The ranges of percentages reflects differences in the type of roads.

A conclusive table is compiled, which extracts the relevant results of the collision type analysis.
1. Background

The model outlined in this paper is concerned with the following broad question: Is it possible to estimate the risk of a release of a dangerous material and the consequences of that release if a load of this material is transported from one point to another? The model is, so far, only concerned with inland transport by road or by rail.

The aim is to develop a risk model in such a form that different transport alternatives could be considered and that the method should allow an optimization of route choice or even the choice of location of a production plant from the point of view of transport safety.

The model structure is developed by Lars Brockhoff (1992, a). He is unfortunately not able to present his work in person so he has agreed to a presentation by the author with whom he has collaborated during the model development.

---

One interesting question is: Is the problem relevant at all? It is well known that environmental authorities in the EC are concerned about the safety of production plants following the Seveso accident (the "Seveso directive" is one EC reaction). It is therefore relevant to compare transport accidents involving dangerous materials to accidents at fixed installations, see table 1.

<table>
<thead>
<tr>
<th></th>
<th>Number of accidents</th>
<th>Accidents with ≥ 1 fatality</th>
<th>Accidents with ≥ 5 fatalities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport</td>
<td>729 (40%)</td>
<td>174 (28%)</td>
<td>67 (37%)</td>
</tr>
<tr>
<td>Fixed installat.</td>
<td>1072 (60%)</td>
<td>442 (72%)</td>
<td>115 (63%)</td>
</tr>
<tr>
<td>Total</td>
<td>1801 (100%)</td>
<td>616 (100%)</td>
<td>182 (100%)</td>
</tr>
</tbody>
</table>

Table 1: The numbers of (road, rail and pipeline) transport accidents and fixed installation accidents involving dangerous goods in all countries after 1959. Loading/unloading accident excluded.
Transport accidents broken down according to transport mode is given in table 2.

<table>
<thead>
<tr>
<th>Transport Mode</th>
<th>Total number of accidents</th>
<th>Accidents with ≥ 1 fatalities</th>
<th>Accidents with ≥ 5 fatalities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road</td>
<td>271</td>
<td>69</td>
<td>26</td>
</tr>
<tr>
<td>Rail</td>
<td>298</td>
<td>42</td>
<td>14</td>
</tr>
<tr>
<td>Pipeline</td>
<td>160</td>
<td>63</td>
<td>27</td>
</tr>
</tbody>
</table>

Table 2: The number of transport accidents from table 1, distributed on transport modes.

From table 1 it is concluded that transport accidents are about as many as fixed installation accidents. There is a tendency that transport accidents develop more seriously than fixed installation accidents. From table 2 it is concluded that the 3 transport modes are about equally important to transport risk. Furthermore, Brockhoff reports that there has been an increase in accidents from 1960 - 74 to 1975 - 90 by about a factor 3 with transport accident increasing more than fixed installation accidents.

The main conclusion from these studies is that the risks associated with transport of dangerous goods are important. The development of a risk model seems worth the effort.

2. Model structure

The model structure is presented in fig. 1. The main idea is to create a model from building blocks which allow the risk estimation through a series of submodels:
- database of road network
- database of rail network
- estimation of road accidents
- estimation of rail accidents
- release rates for road tankers
- release rates for rail tankers
- tank failure consequence distribution.

In order to demonstrate the model the Danish state road and rail networks are used. Data on the road network standards and on car and truck traffic flows are taken from the Danish road data bank.

The model on road traffic accidents is based on about 100 000 road accidents over 5 years distributed on about ten categories of road sections and intersections. The road accident model is
described in detail by Jørgensen (1992) in a paper to this conference.

It has not been possible to create a similarly detailed model for rail accidents simply because of fewer accidents, only 121 rail accidents over 10 years. Different models were tested. At the end an accident rate of $3 \times 10^{-8}$ accidents per train kilometer driven is applied to sections in between stations. At stations a rate of $7 \times 10^{-7}$ accidents per train kilometer driven is applied.

The model for road tanker failure probabilities is based on two submodels. One model describes how tank trucks are likely to be hit by other vehicles. This submodel is based on the analysis of some 18,000 accident reports on Danish truck accidents. The other submodel based on theoretical considerations and literature data expresses the risk of a tank failure given the impact and its direction. Given a release the model provides a conditional distribution of amounts released.

Because of the small amount of data available the rail tank release model is limited to two release probabilities collected
from American publications and a conditional distribution of amounts released.

The consequence model expresses the expected number of fatalities given the amount released of dangerous material. Data suggests that the number of fatalities could be expressed as

\[ N_{\text{pop}} = \beta_{\text{pop}} \times W^n \]  

(1)

where
- \( N_{\text{pop}} \) is the expected number of fatalities
- \( \beta_{\text{pop}} \) depends on population density and material
- \( W \) is the quantity released
- \( n \) is a constant depending on released material

Data for releases of chlorine and ammonia combined with simulation results suggest that \( n \) is in the order of 0.75 - 1.0 so the number of fatalities is roughly proportional to the quantity released. \( \beta_{\text{pop}} \) depends on the surroundings. The classification of surroundings is in this model limited to three categories: urban, semi-urban and rural. These categories are easy to use in combination with the road and rail network data banks where such data are registered. The ratios between \( \beta \)-values urban/semi-urban and semi-urban/rural which express the influence of population density vary from about 3 to 10 according to available data. This indicates as expected that the population density is of major importance for the consequences of an accident. Table 3 gives numerical values for \( \beta \).

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Population density</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Urban</td>
</tr>
<tr>
<td>Chlorine</td>
<td>5.5</td>
</tr>
<tr>
<td>Ammonia</td>
<td>1.2</td>
</tr>
<tr>
<td>LPG</td>
<td>9.8</td>
</tr>
<tr>
<td>Gasoline</td>
<td>4.1</td>
</tr>
<tr>
<td>Diesel</td>
<td>4.1</td>
</tr>
</tbody>
</table>

Table 3: \( \beta \)-values

3. The XTRIM computer model

The total model is implemented on a UNIX based platform which is capable of estimating transport risks for network links and nodes and to select shortest route, fastest route, route with lowest release frequency, lowest cost route etc. between two points in the network. The program (Brockhoff, 1992 b) is menu-oriented and interactive. Results are presented both numerically and graphically.

In order to carry out calculations the program needs information on transport mode, chemical to be shipped, tanker type and quantity to be shipped.
4. Model validation.

A model validation has been attempted. From estimates of quantities of gasoline, diesel fuel and domestic fuel transported by road in Denmark an estimate of large releases of fuel was made. The computed value was 0.5 releases per year which corresponds well with 8 large releases observed through 13 years. Other validations suggest that the consequence model gives results close to those of much more complicated models which are generally accepted.

5. Acknowledgements.

As mentioned above this paper is based on the Ph.D.-thesis by Lars Henrik Brockhoff, reference Brockhoff (1992, a).

6. References.


L. H. Brockhoff may be contacted after 1. December 1992 at

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