Proceedings of ROAD SAFETY AND TRAFFIC ENVIRONMENT IN EUROPE in Gothenburg, Sweden, September 26-28, 1990

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

Papers presented at the seminar were as follows: Opening Speech (Faerm, G); Motorization and Trends in Road Traffic (Lenz, K-H); Traffic Environment - The Nature of the Problem? (Thunberg, B); Traffic Safety Facing Year 2000 - A Challenge for the Automotive Industry (Persson, J C); Use of Simulation to Improve Vehicle Design (Badin, F and Maillard, P); Vehicle Development and Road Safety (Michalik, C); Role of the Motor Vehicle in Traffic Engineering of the Future (Voy, C); Automotive Crash Safety Engineering - Time for a New Approach? (Mellander, H); Daimler-Benz Driving Simulator - Research for Road Safety and Traffic Environment (Schill, V and Käding, W); VTI Driving Simulator - Trends and Experiences (Nordmark, S); Protection Effects of Child Restraints - Experiences from Accidents and Sled Tests with Carry-Cots (Glaeser, K-P, Langwieder, K and Hummel, T).
PREFACE

The Swedish Road and Traffic Research Institute (VTI) and the Bundesanstalt für Strassenwesen (BASt), Federal Republic of Germany, were jointly organizing 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 and Environment, were presented
- vehicles
- city planning
- speed
- vulnerable road users
- future traffic and RTI
- environment
- campaigns and publicity
- information and enforcement

Linköping October 1990

Kenneth Asp

Proceedings of ROAD SAFETY AND TRAFFIC ENVIRONMENT IN EUROPE in Gothenburg, Sweden, September 26-28, 1990:

VTI RAPPORT 262A
- Opening
- Vehicles

VTI RAPPORT 263A
- City Planning
- Speed

VTI RAPPORT 264A
- Vulnerable Road Users
- Future Traffic and RTI
- Environment

VTI RAPPORT 265A
- Campaigns and Publicity
- Information and Enforcement
CONTENTS

<table>
<thead>
<tr>
<th>Program</th>
<th>I</th>
</tr>
</thead>
<tbody>
<tr>
<td>List of participants</td>
<td>VIII</td>
</tr>
</tbody>
</table>

OPENING

Opening Speech

Gunnel Färm, Ministry of Transport and Communications, Sweden

Motorization and Trends in Road Traffic

Karl-Heinz Lenz, BASt, Federal Republic of Germany

Traffic and Environment

- The Nature of the Problem?
  Börje Thunberg, VTI, Sweden

Traffic Safety Facing Year 2000

- A Challenge for the Automotive Industry
  Jan Crister Persson, Volvo Car Corporation, Sweden

VEHICLES

Use of Simulation to Improve Vehicle Design

François Badin and P Maillard, INRETS, France

Vehicle Development and Road Safety

Christa Michalik, Austrian Road Safety Board, Austria

Role of the Motor Vehicle in Traffic Engineering of the Future

Christian Voy, DAUG, Federal Republic of Germany
Automotive Crash Safety Engineering  
- Time for a New Approach?  
Hugo Mellander, Volvo Car Corporation, Sweden  

Daimler-Benz Driving Simulator – Research for Road Safety and Traffic Environment  
Volkhard Schill and Wilfried Kading, Daimler-Benz AG, Federal Republic of Germany  

VTI Driving Simulator – Trends and Experiences  
Staffan Nordmark, VTI, Sweden  

Protection Effects of Child Restraints  
- Experiences from Accidents and Sled Tests with Carry-Cots  
Klaus-Peter Glaeser, BASt, K Langwieder and Th Hummel, HUK-Verband, Federal Republic of Germany
ROAD SAFETY AND TRAFFIC ENVIRONMENT IN EUROPE

Gothenburg, Sweden

September 26-28, 1990

WEDNESDAY SEPTEMBER 26

OPENING

9.30 - 11.30

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

Opening Speeches
Mrs Gunnel Färm, Deputy Minister of Transport and Communications Sweden
Prof Dr Heinrich Praxenthaler, President, Federal Highway Research Institute (BASt), Federal Republic of Germany
Mrs Monica Sundström, Director General, Swedish Road and Traffic Research Institute (VTI), Sweden

Motorization and Trends in Road Traffic
Prof Dr-Ing Karl-Heinz Lenz, Federal Highway Research Institute (BASt), Federal Republic of Germany

Traffic and Environment - What is the Problem?
Mr Börje Thunberg, Research Director, Swedish Road and Traffic Research Institute (VTI), Sweden

Traffic Safety facing Year 2000: Challenge for the Automotive Industry
Mr Jan Crister Persson, Vice President Engineering, Volvo Car Corporation, Sweden
Chairman: Prof Dr-Ing Karl-Heinz Lenz, Federal Highway Research Institute (BASt), Federal Republic of Germany

The Use of Simulation to Improve Vehicle Design
Mr François Badin, Institut National de Recherche sur les Transports et leur Sécurité (INRETS), France

Vehicle Development and Road Safety
Dr Christa Michalik, Austrian Road Safety Board, Institute of Traffic Education, Austria

The Role of the Motor Vehicle in Traffic Engineering of the Future
Dr Joachim Schmidt, Deutsche Automobilgesellschaft mbH (DAUG), Federal Republic of Germany

Automotive Crash Safety Engineering - Time for a New Approach?
Mr Hugo Mellander, Volvo Car Corporation, Sweden

The Daimler-Benz Driving Simulator - Research for Road Safety and Traffic Environment
Dipl Inf Volkhard Schill and Mr Joachim Stritzke, Daimler-Benz, Federal Republic of Germany

The VTI Driving Simulator
Prof Staffan Nordmark, Swedish Road and Traffic Research Institute (VTI), Sweden

Protection Effects of Child Restraints - Experiences from Accidents and Sled Tests with Carry-Cots
Dipl-Ing K-P Glaeser, Federal Highway Research Institute (BASt), Federal Republic of Germany
WEDNESDAY SEPTEMBER 26

CITY PLANNING

13.00 - 16.30

Chairman: Prof Niels O Jørgensen, Technical University of Denmark, Denmark

Traffic Management by Design in One Family Housing Areas
Architect Jens Bjørneboe, Norwegian Building Research Institute (Norges Byggforskningsinstitutt), Norway

Pedestrian Safety and Delay at Crossing Facilities in the United Kingdom
Dr J G Hunt, University of Wales College of Cardiff, United Kingdom

The Safety of Cycling Children. Effect of the Street Environment
Dr Lars Leden, Technical Research Centre of Finland, Finland

Analysis of Traffic Safety regarding Public and Individual Transport
Prof Dr-Ing Uwe Köhler, University of Kassel, Federal Republic of Germany

Urban Traffic Network - A Spatial Approach
Prof Dr S Olof Gunnarsson, Chalmers University of Technology, Sweden

Comparison of Road Safety in Different Cities
Dozent Dr sc techn H-J Neumann, Transport University (Hochschule für Verkehrswesen), German Democratic Republic
THURSDAY SEPTEMBER 27

SPEED

9.30 - 13.00

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

Effects of Speed Reducing Measures in Danish Residential Areas
Ms Ulla Engel, Senior Research Scientist, Danish Council of Road Safety Research, Denmark

A Case Study Evaluating Traffic Warning Devices with Respect to Operating Speeds and Accident Rates
Prof Dr-Ing Rüdiger Lamm, University of Karlsruhe, Federal Republic of Germany

Area Wide Traffic Calming Measures and Their Effects on Traffic Safety in Residential Areas
Prof Dr-Ing Werner Brilon, Ruhr-University Bochum, Federal Republic of Germany

Statistical Distribution of Speeds on German Motorways
Dr Dirk Heidemann, Federal Highway Research Institute (BASt), Federal Republic of Germany

Drivers' Attitudes and Beliefs towards Speed Limits and Speeding on Dutch Motorways
Dr Ton Rooijers, Traffic Research Centre (VSC), The Netherlands

FUTURE TRAFFIC AND ROAD TRAFFIC INFORMATICS (RTI)

(WORKSHOP)

14.00 - 17.30

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

Test Site West Sweden: Learning RTI and Demonstrating Its Usefulness
Mr Lars-Erik Sjöberg, National Swedish Road Administration, Sweden

Future Traffic and RTI. Status report of the Federal Republic of Germany
Dr Ing Jürgen Behrendt, Leitender Regierungsdirektor, Federal Highway Research Institute (BASt), Federal Republic of Germany

Evaluation of the Perspectives of Driving Aids based on Short Range Transmission Links between Ground and Vehicles and between Vehicles
Mr Yves David, INRETS-CRESTA, France

RTI - Current Global Projects
Mr Tage Karlsson, Director, Volvo DRIVE-SECFO, Belgium
THURSDAY SEPTEMBER 27

VULNERABLE ROAD USERS

9.30 - 13.00

Chairman: Prof Dr S Olof Gunnarsson, Chalmers University of Technology, Sweden

Riding a Moped: Acquisition of Basic Skills and Mental Effort
Dr Marcel Wierda, Traffic Research Centre (VSC), The Netherlands

An Intelligent Traffic System for Vulnerable Road Users
Mr Oliver Carsten, Senior Research Fellow, Institute for Transport Studies, United Kingdom

Traffic Related Knowledge, Attitudes and Risk Perception in Dutch Secondary School Children; Consequences for Traffic Education
Dr Jan Brinks, Traffic Research Centre (VSC), The Netherlands

Lifestyle, Leisurestyle and Traffic Behaviour of Young Drivers
Dr Horst Schulze, Federal Highway Research Institute (BAST), Federal Republic of Germany

ENVIRONMENT (WORKSHOP)

14.00 - 17.30

Chairman: Mr Göran Friberg, Director, Swedish Environmental Protection Board (SNV), Sweden

Total Environmental Impact of the Car
Mr Ulf Jansson, Volvo Car Corporation, Sweden

Environment. Status report of the Federal Republic of Germany
Dr Klaus Becker, Federal Environmental Agency (Umweltbundesamt), Federal Republic of Germany

Status report from the Netherlands
Dr M P J Pulles, Center for Energy and Environmental Studies (IVEM), The Netherlands
FRIDAY SEPTEMBER 28

CAMPAIGNS AND PUBLICITY

8.30 - 12.30

Chairman: Prof Dr Günter Kroj, Federal Highway Research Institute (BASt), Federal Republic of Germany

National Road Safety Politics - A Contradictory and Suppressed Field of Decision Making
Ms Karin Køltzow, Research Officer, Institute of Transport Economics (TØI), Norway

Motorway Driving Speed Reduction and the Associated Public Information Campaigns in the Netherlands
Dr Peter Liedekerken, Ministry of Transport and Public Works, The Netherlands

Campaigns against Drunken Driving among Young Drivers
Mr Per Studsholt, Section Eng, Danish Society of Engineers (Nordjylland Amt), Denmark

The Effectiveness of the 1988 Police National Motorway Safety Campaign
Ms Nicola Christie, Transport and Road Research Laboratory (TRRL), United Kingdom

Improvement of Traffic Safety by Local Public Relations Campaigns
Dipl-Ing Klaus Schlabbach, Town Planning Authority Darmstadt (Bauderzernat Stadtplanungsamt), Federal Republic of Germany

A Comedy on TV to Promote Traffic Safety
Dr R D Wittink, Institute for Road Safety Research (SWOV) and Dr W J A Nelissen, Research & Marketing, The Netherlands

Road Safety as Business - Vision or Reality? The Brazilian Example
Mr J Pedro Correa, Volvo do Brasil, Brazil
FRIDAY SEPTEMBER 28

INFORMATION AND ENFORCEMENT

8.30 - 12.30

Chairman: Prof Dr Karl-Heinz Lenz, Federal Highway Research Institute (BASt), Federal Republic of Germany

A New Way of Broadcasts for Motorists
Mr Walter Melchers, Der Innenminister des Landes NRW, Federal Republic of Germany

Automatic Monitoring and Enforcement of Traffic Highway Violations
Mr Nicholas Ayland, Castle Rock Consultants, United Kingdom

Can Road Traffic Law Enforcement Permanently Reduce the Number of Accidents?
Mr Torkel Bjørnskau and Mr Rune Elvik, Research Officer, Institute of Transport Economics (TØI), Norway

A Vehicle Accident Data Recorder
Dr William Fincham, Queen Mary and Westfield College, United Kingdom

Enforcement: The Scope for Automotive Detection and Information Systems
Dr Talib Rothengatter, Traffic Research Center (VSC), The Netherlands
List of participants Road Safety and Traffic Environment in Europe September 26-28, 1990

<table>
<thead>
<tr>
<th>Name</th>
<th>Institution</th>
<th>Country</th>
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<td>Aarnikko Tenho</td>
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<td>Newspaper Vi Bilägare</td>
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List of participants Road Safety and Traffic Environment in Europe September 26-28, 1990

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<thead>
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<th>Name</th>
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VTI RAPPORT 362A
List of participants Road Safety and Traffic Environment in Europe September 26-28, 1990

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Opening Speech

Gunnel Färm
Under-Secretary of State
Ministry of Transport and Communications
Sweden
Speech by Under-Secretary of State Mrs Gunnel Fåhrn at the Road Safety and Traffic Environment Conference held by the VTI and BAST, September 26, 1990

Ladies and gentlemen,

Traffic and transport are crucial to the development of society. Fast, safe, high-capacity communications are essential for industrial development both in Sweden, in Germany and in other countries.

The dramatic events in Europe in the past year have given us a vivid reminder of this fact. The coming of freedom to Eastern Europe has at last opened up opportunities for the people there to satisfy their desire to travel. The growth of trade has increased the need of transport capacity and new routes have been established. But at the same time the bottlenecks in the transport system have become plain for all to see.

The ongoing process of integration in Western Europe has had the same effect. European integration is based on the principle of freedom of movement for people, capital, goods and services. Here again, a well-developed communications system is essential.

The role of transport may be compared to the circulation of blood in our bodies, but just as circulatory disturbances involve a risk of heart attacks, congestion, emissions of noxious gases and accidents are ever-present hazards in the traffic environment. These are the subjects of this conference, which offers a welcome opportunity to exchange ideas and information and to learn more about the environmental impact of traffic and about road safety.

Let me start by outlining the Swedish Government’s views on road safety and the environmental effects of traffic.

First of all, it must be said that the environmental problems caused by traffic in our country are relatively small. Sweden is a large country by European standards and most of it is rather sparsely populated. Therefore, the problems are mainly to be found in the urban areas, in particular the three largest cities, Stockholm, Gothenburg and Malmö. However, this does not mean that we can sit back and take things easy. We must pursue our efforts to reduce the adverse effects on the environment, bearing in mind that the progress we make now will help to prevent problems arising in the future.

The Government’s strategy for a cleaner traffic environment comprises four basic elements:

- cleaner vehicles
- international cooperation
- a better transport structure
- cleaner cities
I intend to say a few words about each of these goals.

1. As you will all have heard many times: cars are here to stay. They have given us greater freedom and prosperity and ample opportunities to make the most of our leisure time. They are also essential for the distribution of goods and services, and for many people, especially those living in rural areas with great distances between population centres, they are an indispensable means of transport. Therefore I say: cars in themselves are wonderful. It’s the pollution they cause that is the problem.

So cleaner motor vehicles are an essential part of any strategy to reduce the pollution caused by the transport sector. As we see it, the Government’s job is to set the emission standards and it is up to the car industry to find the technical solutions.

However, establishing these standards is not always as easy as it may sound. Stricter emission standards are usually met by objections such as: they won’t work, they will cost too much, and so on. But once the standards have been set, it usually takes a surprisingly short time to develop the necessary technology.

2. Sweden is a small country in terms of population, and we cannot go ahead and establish emission standards on our own. Even if we did, it wouldn’t help, since air pollution is transboundary by nature.

Therefore we are doing what we can in international fora to bring about binding decisions on stricter emission limits and standards. An important aim in this connection is to create an opinion for concrete measures relating to the traffic environment.

One important international forum is the ECMT, the European Conference of Ministers of Transport. The Swedish Minister of Transport, Mr Georg Andersson, is currently chairman of the ECMT, and one of the initiatives he has taken has been to invite the international automotive and fuel industry to a hearing on cleaner vehicle technology. The hearing will take place at the end of November.

3. The development of the transport structure as a whole is determined by the infrastructure, investments in transport and coordination between the different means of transport. One important factor of course is a vigorous policy to make rail transport and public transport in general an attractive and competitive alternative to cars. Rail transport is an economic and efficient means of mass transport for both passengers and freight. New systems for freight transport must be developed, in particular, systems combining rail transport with road and sea transport.
As a matter of principle, each transport sector should pay its way. In other words, taxes and fares should cover the fixed and variable costs, i.e. the total cost to society, of each sector.

One significant way of cutting transport costs is to reduce transport needs by better coordination between the planning authorities responsible for housing, workplaces and communications.

4. With respect to the large cities - if we can call our three largest cities large in a European context - the Government's view is that their traffic and transport problems should be treated separately. Basically, the solution to the problems of the cities is to reverse the trend of ever-increasing traffic.

This can be done in several ways. Various systems of charges or tolls have been considered as a means of reducing traffic in Stockholm’s inner city. The construction of more orbital and relief roads is another alternative. But upgrading the public transport system remains the number one priority. In my opinion, the most important thing is to win over the commuters by providing comfortable, fast and frequent public transport services.

Now to the question of safety. Without wanting to sound complacent I feel that we are justified in saying that in this area too we have a satisfactory record by international comparisons. But a great deal still remains to be done. We can never be satisfied as long as people are killed or injured in traffic accidents or suffer from the traffic environment.

Measures to improve road safety can be directed at three different targets: the drivers, the vehicles and the roads. And let's admit it: the drivers are often the weakest link in the chain.

To my mind, the only solution to the increasing anarchy on the roads is a radical change of attitude among drivers. Education is a decisive factor in our efforts to improve road safety. It is the most important means of changing attitudes. By changing drivers’ attitudes we can also change their behaviour on the roads.

But of course it is equally important to ensure that drivers acquire the right attitude from the start, even before they take to the roads. Young drivers, eighteen- and nineteen-years-olds, run the greatest risk of being involved in accidents. This age group accounted for 12 per cent of all deaths and injuries on the roads in Sweden in 1988. Young drivers account for a higher than average percentage of both one-car accidents, accidents at night and alcohol-related accidents.

We know that one reason for this is the young drivers' lack of experience. We also know that younger drivers have a more tolerant attitude towards breaking the rules.
Several measures have been taken in Sweden to remedy this state of affairs. We have recently introduced a two-year provisional licence for those who have just passed their driving test. We have also introduced an new syllabus and a new driving theory test. Our intention has been to shift the emphasis of driving instruction from learning by heart to real understanding.

The sharp increase in traffic in recent years has also increased the demands on drivers. New patterns have emerged. Women and elderly people now account for an increasing percentage of drivers. In view of these developments the Swedish Government has found it necessary to review the regulations applying to driving licences and instruction once again. A Parliamentary Commission has been appointed to study various aspects connected with driving licences, i.e. instruction, different classes of licences, periodic tests, etc.

In the last analysis, road safety is a question of civilized behaviour to our fellow citizens. I believe we must start talking more about traffic morals, which does not necessarily mean we should moralize on the subject. We must pluck up the courage to change our habits. After all, the only way of improving the situation as regards road safety is by personal commitment, taking responsibility for our actions and setting a good example. Those of us who are responsible for road safety must set the trend in these respects.

Lastly, personal responsibility and commitment are also significant factors when it comes to doing something about the environment. Those of us who live in the rich industrialized countries of the western world must assume personal responsibility that goes beyond the obligation of merely complying with the basic rules imposed by society.

I would like to finish by expressing my satisfaction at having had the privilege of opening this conference. I hope it will prove rewarding: its subject is certainly a very important one.
Motorization and Trends in Road Traffic

Karl-Heinz Lenz
Prof Dr
Federal Highway Research Institute (BASt)
Federal Republic of Germany
Motorization and Trends in Road Traffic

According to UN estimates, there were roughly 5.1 billion people on our planet in 1988. The number of motor vehicles available is estimated at 534 million, of which 408 million are cars. The present worldwide vehicle density therefore amounts to about 1 car per 12 persons.

Motor vehicles, however, are still far from being evenly distributed around the globe. Whereas in the US there are presently about 575 cars per 1,000 inhabitants, there are still only 9 in Egypt, 240 in Japan and 438 cars per 1,000 inhabitants in Australia. It should be noted, however, that in the less motorized countries car ownership alone is not the only indication of the degree of motorization. In these countries, motorcycles or mopeds are also important means of transport.

There are, however, great differences also in Europe: about 345 million people are living in the Western European countries. More than 127 million cars are at their disposal, that is to say 369 cars per 1,000 inhabitants. In the Eastern European countries, with a population of 318 million, motorization is much lower. In Poland, for instance, there are 112 cars per 1,000 inhabitants, and 51 in the European part of the Soviet Union.

Will things remain as they are, or are we facing a latent demand here? Do people in the closing years of the 20th century need to own a car to maintain a certain status? Will everyone on this earth try owning a car eventually? Or even two in the wealthy countries, one for the city and one for longer distances? Then why not three—the additional one for recreation purposes—or still more cars? Will people of the 21st century in these countries then have about as many cars in their life as they now have suits in their closets, even though only one can be worn at any one time?

There are no simple answers to this question. To look into the future and come up with the right predictions regarding impending developments is something nobody succeeds with very well. It would also deprive us of the chance of making active efforts to improve our situation. Realistically speaking, a look into the future invariably involves the question about what happened in the past and how things will develop if left to go on as they did before. This has also motivated a look at the present in order to investigate the reasons why it has become what it appears to be to us now.

As shown in a survey of 1982, an average of 150 million trips were made in the Federal Republic of Germany every day by just under 62 million people. This refers to the trips made by the...
German residential population from the age of 10 years, that is to say without servicemen in barracks, people in old-age homes, etc, and without those on holiday and business trips³).

As you will see now on the first slide, the car is the most important means of transport for the residential population for getting from A to B. Roughly 45% of all trips are made as driver or passenger of a car. Nearly 30% of all trips are made on foot, roughly 10% by bicycle, and 10% again by public transport.

As shown on the next slide, trip purposes, with a proportion of 30%, are almost evenly distributed among recreation, work, and shopping and supply. With a proportion of 8.5% of all trips, education comes fourth on this list.
In respect of the distribution of trips according to the means of transport and purpose of trip, the next slide shows that the car predominates as the means of transport on the way to work and for recreation purposes, and that the trips to places of education and to shops are still mainly made on foot.

This rough first analysis of the choice of transport modes will suffice here to make clear that there are still potentials for growth in motorization, even in Germany.

Mere car ownership does not create problems for society, apart from the parking problem in the centre of cities. The situation becomes critical, however, as soon as the car is being put to use.

In 1960, vehicle travel on the whole amounted to 110 milliard kilometres in the Federal Republic of Germany. In 1970, it had gone up to 234 milliard kilometres, then rose further to 342 milliard kilometres in 1980, and kept growing, reaching 427 milliard kilometres in 1988. Within a span of about 30 years, vehicle travel has quadrupled. What is particularly striking when considering this development is the increase in vehicle travel not at constant percentage rates but by a constant absolute amount of, on average, 10.5 milliard kilometres per year.
Today, about 1.2 milliard kilometres are covered by car in Germany each day - an inconceivably high figure. Let me try helping you getting a better grasp of it: if you take 120,000 kilometres as the average service life of a car today, vehicle travel of 1.2 milliard kilometres will correspond to the average travel of 10,000 cars over their service life, that is to say if we take these 10,000 cars to represent our daily vehicle travel, they will start out brand-new in the morning and be fit for the scrapyard in the evening. However, 10,000 cars are still too many for an easy picture. What we can picture is a traffic jam on the autobahn, cars at a standstill over a length of 35 kilometres in both lanes in the direction of travel. That too will be about 10,000 cars. Applying this image to the vehicle travel per day in the Western part of Europe, cars would queue up for about 165 kilometres.

The development on our autobahns was even more dramatic than on all other roads in Germany: between 1970 and 1988, that is to say within a period of not even 20 years, annual vehicle travel rose from 35 milliard kilometres to 121 milliard kilometres, which amounts to an increase of 246%. Nearly one-third of the entire vehicle travel takes place on autobahns at present, 15% of this by truck. The traffic volume on autobahns displays an annual growth rate of just under 6%. A consideration on how to cope with autobahn traffic growing at such a rate would be worth to be made a subject of a separate paper.

Mobility in our country is not evenly distributed among car owners. According to a study undertaken by the Roland Berger Research Institute in 1987, the average annual vehicle travel of cars at present amounts to 14,300 kilometres. This value is reduced to 13,500 kilometres for cars owned for private use. It amounts to 19,100 for commercial cars. There are also differences depending on the kind of car used. A car with an Otto
engine travels on average 13,700 kilometres per year, with a Diesel engine 18,300 kilometres. A car with an engine capacity of less than 1 litre, 10,900 kilometres, and one with an engine capacity exceeding 2 litres, 17,600 kilometres.

Age of drivers also affects mobility to a very great extent: Those under 25 years of age, travel with 17,000 kilometres per year more than twice as much as the elderly over 65 years with
8,300 kilometres. However, there are now many more elderly car drivers on our roads than in the past. During the six years from 1976 to 1982, vehicle travel of this group on the whole increased accordingly by a good 80% (81.4%) 3. Compared with that, the overall vehicle travel in the same time period only rose by 15%. With an annual travel of on average 13,300 kilometres, women also do not drive as much as male car drivers do (15,600) 4. But there is a dramatic development here too. Since there are now as many female as male applicants for the class-3-driving-licence 5 and since women also increasingly are behind the wheel, a little less than one-third (30%) 6 of the total passenger car travel now falls to the share of female drivers.

The opening up of the borders in Eastern Europe will quite certainly also influence the mobility of people. No country in Europe will however be as strongly affected by this development as the Federal Republic of Germany and the German Democratic Republic. Let me offer a few considerations in this connection:

Let us assume - which is a realistic assumption - that each car owner of the German Democratic Republic drives 1,000 kilometres, on average, in 1990 on trips to the Federal Republic. This would add roughly 4 milliard kilometres to the vehicle travel in the Federal Republic. Based on the overall vehicle travel of the Federal Republic in 1990 of about 450 milliard kilometres, the additional increase would be less than 1%. Since we are expecting an increase in vehicle travel of 3% this year at any rate, an overall increase of 4% will not be so much more by comparison.

It is different for the German Democratic Republic: if only every third car owner of the Federal Republic of Germany were to go on a trip to the German Democratic Republic in 1990, driving about 1,000 kilometres, this would add about 10 milliard kilometres to the vehicle travel of the German Democratic Republic, increasing it by 25% based on the overall vehicle travel of about 40 milliard kilometres of that country. In addition to this increase of 25%, there will also be a considerable increase due to additional vehicle travel by car owners of the German Democratic Republic. We know from relevant sources that people in the German Democratic Republic, on average, used to drive no more than 10,000 kilometres per year. In the Federal Republic of Germany, the average for a car lies just under 15,000 kilometres per year. The closed borders of the German Democratic Republic had the effect of making travel by car less attractive than it is for us. This, however, is no longer the case and there is every indication that vehicle travel in both countries will even out at the level of about 15,000 kilometres as the two states grow together. This would imply a further increase in vehicle travel by 50% so that the overall increase in 1990, compared with 1989, should be more of the order of 75%. This still does not take the increase in vehicle travel resulting from the increase in motorization into account: in the district of Schwerin, German Democratic Republic, there were reportedly about as many new cars registered during the first quarter of 1990 as during the entire previous year.
Exact vehicle travel figures are not yet available. However, if we consider fuel consumption in the German Democratic Republic as an indication of vehicle travel, it is safe to assume that the estimates above will be even surpassed. In the first four months of 1990, fuel sales figures in the German Democratic Republic rose by 90% compared with the same period of the year before. That this type of mobility in the German Democratic Republic will also have its negative aspects has quickly become apparent: the accident records of the police rose by more than 60% during the first half of 1990 compared with the same period of 1989.

Even more dramatic than expressed by these figures have been the changes in traffic in the border areas. The roads and autobahns in those areas, which until recently ended at an impenetrable wall and where people had enjoyed peace and tranquillity, now carry as much traffic as any urban highway. It does not need to be mentioned in particular that Berlin(West) with its previous insular position is quite extraordinarily affected by this development.

On the whole, however, the opening up of the borders in Eastern Europe has effected a sudden increase in mobility in the West to a far lesser degree than in the East. Aside from some regional bottlenecks, the effects in Eastern Europe are still manageable because vehicle travel and motorization were below average before. With the dramatic development of mobility, this will however change very quickly, unless measures are taken to improve the road infrastructure before long.

How will motorization in the Federal Republic of Germany continue to develop?
According to the most recent SHELL forecast (it should however be mentioned that all previous SHELL forecasts were surpassed by the developments actually taking place), the car population within the area of the present Federal Republic of Germany will increase to 34.7 million vehicles till the year 2010, provided the economic development continues in a positive manner. Only in the case of an economic disharmony will the car population stop at 30.5 million. All these assumptions are based on the expectation that the population from the age of 18 years will more or less remain constant. At some 570 cars per 1,000 inhabitants, we will then have as many cars per inhabitants as there are now in the United States of America. Vehicle travel will also grow vigorously, unless it is checked by state policies. In this connection, it may also be of interest to note that the trend towards the powerful car still continues: whereas in 1970 the percentage of cars with an engine capacity exceeding 2 litres still had been 5.4%, it reached 14.4% in 1989 and has thus almost tripled. In contrast to that, the percentage of small cars with an engine capacity under one litre went down from 14.5% to 6.9%. However, attaining 2.0 million in 1970 and 2.1 million in 1989, the population of small cars in absolute terms has remained nearly constant.

Also in Europe, developments have not come to a standstill yet. A look at the development of motorization in some of the important Western European countries still shows an unbroken upward trend. Vehicle travel shows a similar trend, and with the opening of the borders in Europe in the next years even heavier increases can be expected. But even in the Western part of Europe, there are differences in motorization so that the growth rates in the countries will not be the same.
And what does the worldwide situation look like?

If average annual vehicle travel per inhabitant is plotted over the gross national product per capita of a country, the result according to a World Bank study will be a remarkably linear relationship, provided one uses a logarithmic scale. The purchase and the operation of cars is obviously still very much influenced by the economic situation not only of an individual but also of a country.
If we were to succeed in creating a balance between the presently persisting great economic differences from North to South and East to West and in raising the standard of living of the people considerably, then what would be any longer in the way of their buying a motorized vehicle or even a car? However, also in the highly motorized Western countries, motorization will advance as indicated, for instance, by developments in the US and Europe. To what extent people can be fascinated by owning a car produced to Western standard can now be studied in the German Democratic Republic where great efforts to convince people of the necessity of using public transport have been made over a span of 40 years. Whether we then, for other reasons, will still be able to afford worldwide mobility with, say 1, 2 or 3 milliard cars deserves further consideration, for instance, for reasons of environmental protection or energy consumption. Speaking in social terms, we do not know of any country in the world at present where people in the majority are against car ownership or the operation of cars.

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Traffic and Environment - The Nature of the Problem?

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Traffic and Environment - What is the Problem?

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ABSTRACT

Traffic and transports are vital for the functions of our society. At the same time they do constitute a threat against our health and the environment. Great attention has been paid to air pollutions. To reduce the emissions from traffic is urgent. In order to create action plans against air pollutions a number of facts and circumstances must be faced. These circumstances do complicate the search for an optimal action plan.

The purpose of this lecture is to account for and comment on some of these circumstances. For example:

- The changing nature of the problem.
  From being a problem of lead and carbon monoxide, the focus has more and more become emissions of nitrogen oxides and carbon dioxide. What will be the next development? Extended and deepened knowledge often leads to a revised approach to problems, threat scenarios and conceivable action programmes. Environmental work must be regarded as a process in which new results from studies and research, for example, may change the content and implementation of action plans against air pollution.

- Many dimensions and cross-connections between targets, resources and interested parties
  There is a risk that the environmental aspect, which is important, becomes too dominant and obscures the view of the whole.

Traffic and the environment is a problem and subject area with many dimensions. In general, there are no simple, straightforward and uncontroversial answers or solutions when it comes to choosing countermeasures or action programmes against air pollution. Several explanatory circumstances may be pointed out in this context, one of the main ones being that most - if not all - countermeasures and actions aimed at reducing the effects of emissions/imissions often have consequences apart from those which are primarily intended.

- The estimated values for future emissions are very uncertain
  There is always a risk of underestimating or overestimating the problem of emissions, with the accompanying risk of incorrect use of resources against emissions.
1. Introduction

Transport - i.e. the movement of people and goods - has always been and will continue to be decisive for society to function. Regardless of the perspective we choose - the individual, the household, the company or the state - the transport system is one of the cornerstones in the structure of our society.

Today's transport systems - both the physical component, such as vehicles, roads and streets, road users etc, as well as the more abstract component in the form of legislation, systems of regulations, taxation etc - are a result of a process that has been unbroken since ancient times - a process in which many actors and interested parties have interacted and competed. Apart from the primary requirement - the physical movement of people and goods - the transport system has to fulfil a number of other functional demands. These may apply, for example, to safety, regularity, speed, accessibility, availability and energy consumption. The formation and development of our transport apparatus are also largely determined by a number of limiting factors such as availability of land, topography and financial resources.

The transport system serving today's road users and transport purchasers can be regarded as a compromise between the valuations and desires of different interested parties. Motorists as opposed to cyclists and pedestrians, rail traffic as opposed to road traffic, those living close to motorways as opposed to motorway users and so on. At the same time, our present transport system should also be seen as the result of the efforts of traffic planners and politicians to find efficient solutions to our collected need for transport.

There are, however, a number of circumstances indicating that there are, and always will be, shortcomings and defects in our transport system. Among other things, there is always a risk that a solution chosen today will sow the seeds of tomorrow's problems. Looking at the technical breakthrough and development of motoring, we can see that the internal combustion engine has always been, and for the foreseeable future will continue to be, almost the sole source of power for motor vehicles. How many seriously imagined or predicted during the first decades of this century that emissions from the combustion engine would become a threat to our health and environment?
Today, there is no-one who disputes the fact that traffic emissions contain substances injurious to our health and environment. In very simplified terms, we can say that the current debate in Sweden deals with two matters - the seriousness of the threat scenario and the choice of suitable measures to reduce or preferably eliminate the threat.

2. How to formulate the problem?

Let us regard traffic and transport as a process in which the physical movement of people and goods takes place subject to the requirement that a number of subsidiary conditions be fulfilled. These subsidiary conditions are of varying nature and may - depending on who formulates them - span a wide horizon. They may, for instance, apply to such diverse aspects as traffic safety and the financing of transport. Thus it might very well be expected that society or public transport companies adopt the goal, for example, that traffic safety, measured in accidents per million vehicle kilometers, must not exceed a certain level and that public transport must not be subsidised with taxpayers' money more than to a certain percentage.

Theoretically, we can regard the traffic process as a problem of automatic control engineering in which a number of "set point" values have to be fulfilled. For the sake of simplicity, we will assume in the following that the particular "set point" values relate to traffic emissions. As an example, we can take the requirements on emissions. In Sweden today, there are requirements both on individual emissions and on the total emissions from the transport sector. Table 1 contains an example of the requirements currently applying in Sweden.

<table>
<thead>
<tr>
<th>Requirement on individual vehicles (Certification for passenger cars)</th>
<th>Nitrogen oxides</th>
<th>Hydrocarbons</th>
<th>Carbon monoxide</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0,62 g/vehicle km</td>
<td>0,25 g/vehicle km</td>
<td>2,11 g/vehicle km</td>
</tr>
<tr>
<td>Requirement on total emissions from the transport sector</td>
<td>Emissions in 1995 to be 30% less than in 1980.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Example of current (1990) limits on emissions in Sweden.

Essentially, the question of traffic emissions is a simple one. If the emissions on the individual or total level exceed the limits in Table 1, action will be required. In this context, we can apply a chain of reasoning as in Figure 1.
Figure 1. The road traffic planning, construction and maintenance process.

The first step is to decide whether emissions exceed the limits or not. If not, then obviously no action is required since we have reason to assume that the system (the traffic process) is in equilibrium, i.e. within permitted tolerances. However, if it turns out, for example, that the total emissions of the transport sector exceed the limit, action and/or changes will be necessary. In the latter case, we will find ourselves in block II in Figure 1. We have to decide what measure or combination of measures is most cost-effective in order to reduce the emissions to permitted levels. After analysing and evaluating various conceivable action packages, the package considered most cost-effective is implemented. We will now be in block III in Figure 1. As the actions are successively implemented, the actual emissions, i.e. the situation according to block I, should be influenced in such a favorable direction that emissions remain within the limits. If this is not the case, we will have to reiterate the loop shown in Figure 1.

Following the above theoretical considerations, it is time to link up again with the title of this paper: "Traffic and the Environment - the Nature of the Problem". In itself, we could content ourselves by stating that we encounter problems with emissions since they contribute, among other things, to acidification and overmortality from cancer. Therefore, it is important to reduce emissions. However, this type of interpretation and approach to the problem is too shallow and provides no support in facing the real decisions as to what must actually be done to reduce the effects of emissions.
In fact, there is no clear answer to the question of the nature of the problem. Depending on the starting point chosen and the values adopted, there are a number of approaches to the area of traffic and the environment. As is shown in the next section, it is possible to isolate certain facts and circumstances that must reasonably be taken into account in the design of action plans against emissions and air pollution. The major difficulty lies both in distinguishing and defining relevant circumstances and also in the method by which we measure the weight of disparate facts and circumstances.

Putting a point on it, we can say that the problem is that we are unable clearly and uncontroversially to distinguish and formulate what we believe to be a problem.

3. **Circumstances complicating the possibilities of distinguishing and defining the basic problem**

A great deal can be said about the relations, sequences and conditions complicating the picture when making decisions on action against emissions and air pollution. The following describes a number of the factors that in my view complicate the nature of the problem and offer no clear-cut answers or solutions.

The threat scenario is changing

From being a lead and carbon monoxide problem, the focus has to an increasing degree been directed at emissions of nitrogen oxides. What will follow next? Will it be found that long-term exposure to heavy hydrocarbons is a health problem considerably more serious than was earlier thought?

It is something of a truism to state that the choice of action is governed by the problem to be solved. Nevertheless, there is reason for commenting on the connection between action and air pollution problem. In order to produce efficient action programs, we must have a good idea of the threat scenario. Taking action against air pollution without all-round knowledge of the injurious effects of different substances leads to the risk of ineffective programs and thereby the risk of wastage of resources. At the same time, we cannot, if the damage is irreversible and increases with time, postpone action until a firm knowledge base has been built up. Our dilemma is that we have to act now, using our present knowledge base, even though future research may give us a different perspective on the threat scenario and thereby a different assessment of what constitutes effective countermeasures. However, in the case of certain highly publicised environmental problems, the knowledge base is such that constructive action can be taken already at this point in time.

Where to set the limit or target level?

One of several environmental targets in Sweden concerns the total emissions of nitrogen oxides. The Swedish Parliament has decided that NO\textsubscript{x} emissions in 1995 are to be at most 70\% of the level in 1980. A major complication is the consequence that there is reason for questioning whether the reduction of 30\% is sufficient to avoid damage
to the environment. If, as many ecologists assert, the reduction should be up to 75% instead of 30%, there is a risk of inefficient allocation of resources.

To illustrate this in a highly simplified manner, we can assume that the relation between the cost of executing an action and its effect in reducing emissions follows the curves shown in Figure 2.

![Figure 2. Relation between effect and cost of an action. General diagram.](image)

If it is correct that a 30% reduction in emissions is satisfactory, action A should be chosen. Should a reduction of 50% be required, action B should be chosen, since the cost of action B is lower than for action A. With a requirement of 70%, action A cannot even be considered.

If we believe in year 0 that a 30% reduction will be sufficient, we will choose action A, since this is most cost-effective. The problem is that in perhaps five years' time, we may realise that far more powerful action is required and the work of implementing action A may have not been the best one.

Environment is one aspect among many. Traffic and the environment is a problem area and topic of debate with many dimensions. As a rule, there are no simple, clear and uncontroversial answers or solutions when it comes to choosing individual actions or action programs against air pollution. It is possible to point out several circumstances explaining this situation. One of the main reasons is that most, if not all, actions and remedies for reducing traffic emissions lead to consequences apart from those originally intended. A higher gasoline tax, for example, most likely leads to reduced emissions, at the same time as it may
jeopardise goals and ambitions in labor market and regional development policy. Lower vehicle speeds influence not only emissions, but also fuel consumption, traffic safety and vehicle noise.

For the road and traffic planner, it is both important and necessary to consider all aspects and consequences connected with the introduction of a measure. Even if the environmental aspect is important, there is a risk that it may become too dominant and cloud the overall view.

Large variability in calculated effects of action

Figure 3 is taken from a Swedish study in which road traffic emissions were studied in different scenarios. By applying different values to the specific emissions of vehicles, economic growth, taxes and vehicle duties, as well as to the range of public transport available, it was possible to combine them in various ways to create different scenarios.

Figure 3 shows clearly how the results of the calculations depend on the assumptions made.

![Figure 3. NOx emissions from road traffic.](image)

The environmental targets set by the Swedish Parliament - a reduction of 30% by the year 1995 and 50% by the year 2000 - can be achieved by road traffic in the ENVIRONMENT scenario. The LOW scenario would also meet the considerably more stringent requirements of ecologists by the year 2015. However, the REFERENCE scenario is above the environmental target set by Parliament, although the 30% target would be met before 2000. The HIGH scenario - which has higher traffic growth than other scenarios - meets none of the environmental targets set.

The scenario technique as presented in Figure 3 is an excellent aid in demonstrating possible developments. It provides a basis for decisions on the type of control, both "stick" and "carrot", that society should apply.
4. **Concluding remarks**

A complex process lies behind harmful effects on health and the environment as a result of traffic emissions. The effects of emissions on health and the environment are the result of many sub-processes that have been scientifically studied within various disciplines. We can distinguish the following principal components in the process.

![Figure 4. Simplified example of cause and effect relations.](image)

From the aspect of risk and injury, it is the level of emissions contents or deposition that is of primary interest. Therefore, and also because Swedish road traffic accounts for only a small part of this deposition, the targets set up by Parliament for permissible emissions should be seen as necessary but insufficient.

Traffic and the environment is - as stated before - a problem and subject area with many dimensions. In general, there are no simple, straightforward and uncontroversial answers or solutions when it comes to choosing countermeasures or action programmes against air pollution. Several explanatory circumstances may be pointed out in this context, one of the main ones being that most - if not all - countermeasures and actions aimed at reducing the effects of emissions/imissions often have consequences apart from those which are primarily intended. A higher gasoline tax, to take one example, would almost certainly lead to reduced emissions, at the same time as there would be a risk of counteracting objectives and ambitions in labour market and regional development policy.

In general, we consider that in choosing countermeasures against air pollution we must take into account the following circumstances.

- The variety of interested parties and actors each with their own different valuations, targets and choice of countermeasures.
• The changing nature of the problem. From being a problem of lead and carbon monoxide, the focus has more and more become emissions of nitrogen oxides and carbon dioxide. What will be the next development? Hopefully, there will be more interest in a general approach to the issues, so that countermeasures in Sweden against air pollution from traffic will be seen in the perspective both of other domestic sources of pollution and also in the international context.

In the light of the above, we must emphasize the need for further, intensified research. In general, work should be carried out on a broad front and address many issues.
Traffic Safety Facing Year 2000
- A Challenge for the Automotive Industry

Jan Crister Persson
Vice President Product Engineering
Volvo Car Corporation
Sweden
Traffic Safety Facing Year 2000 - a Challenge for the Automotive Industry

Good morning ladies and gentlemen. I am honoured to be here because I believe that your conferences are very important for global advancement in the field of safety.

Safety is and shall remain a cornerstone for us at the Volvo Car Corporation. We are determined to continue to encourage research and development into the next century.

The conditions and opportunities in the automotive industry of tomorrow are going to be determined by many new prerequisites. There will be many difficult challenges to overcome.

We shall solve the problem of unacceptable crowding and continued damage to culture in urban environments; we must conserve energy and use and reuse raw materials wisely. The negative environmental effects of the automobile must be reduced. We are also going to be confronted by new expansive markets with new infra-structures and a great demand for new technology — in Eastern Europe and many developing countries, for example.

These are difficult problems to be sure, but not insurmountable ones. Complex problems have a peculiar way of stimulating creativity and resourcefulness among talented technicians. And I am sure, therefore, that together we will overcome the challenges ahead of us. In some instances, we are already well on the way.

Of course my point of departure is that the automobile is going to remain an important method of transport for people. Partly in its traditional form and also in a completely new form.
We are going to see typical city cars; clean, quiet and extremely economical on fuel. And, we are also probably going to see hybrid cars, i.e., vehicles that can be run on different power sources. Imagine, for instance, a car that uses a traditional internal combustion engine outside cities and electric batteries inside cities.

Cars will be safer because of advanced technology and improved design.

All these things put new demands on those of us who work in the automotive industry; there are demands from customers, government agencies and environmental concerns. The question is how to meet these demands.

The key is an overall view of the situation.

We must continue to build on the idea of driver, car, road and traffic as a system in which all four components have to be considered when things are changed or improved.

An overall view of any situation must always begin with man himself. We must not be blinded by technology and systems so that we forget that it is the driver and his or her way of driving which determines the degree of traffic safety.

That is why it is good that the discussions include how to lessen the use of drugs and alcohol, how to solve the problems of the tired drivers in traffic, how to control the special risk groups which are responsible for a high percentage of accidents.

Although we can, and are going to, include a considerable amount of helpful equipment in cars, we must never lull ourselves into thinking that we have solved the problem of the driver as a risk factor by doing so.

The clear-cut aim of the automobile industry in the 1990s must be to offer drivers even safer cars than it does today.
In striving to achieve this, there are some important questions to be considered.

First, basic biomechanical research at universities, research institutes and industries around the world must not be allowed to become stagnant.

The improvements in car safety that have been achieved in the past decades should not hinder continued research. Research must go forward to better our understanding about how injuries develop. We have to learn more about how injuries occur in the spine, the brain and nerve cells, to name but a few areas of priority. Such basic research must be accelerated if we are to move ahead with automotive research and development.

Second, it is important that the legal requirements, which today control the basic level of safety which all cars must meet, should not make new technical development more difficult. The legal requirements should leave room for optimization, innovations and new approaches.

A global harmonization of these technically complicated and, hence, expensive certification procedures should be carried out as soon as possible, in order to reduce costs and permit resources to be better used for automotive product development.

Hugo Mellander, head of Safety Development at the Volvo Car Corporation, will talk about these issues today during the conference.

Third, it is important that the information about a car's safety features given to owners and prospective customers is relevant information.
The impartial consumer information collected about car safety today — through crash tests, expert evaluations, studies of actual traffic accidents, for example, must measure the actual safety of cars. Otherwise, there is a danger that customers will be misinformed or that the car industry, in its eagerness to receive good marks on these tests, will suboptimize its products.

Ladies and gentlemen, allow me to point to some areas where we can expect to see continued technical development before the year 2000:

The seat-belt which was developed and introduced by Volvo. It remains the most common and the best protection for driver and passenger alike. There is every reason to believe that it will also be found in cars after the turn of the century in combination with airbags, pretension systems, automatic height adjustment etc. This is a good example of how basically simple systems can be developed in logical steps to provide an increasing degree of protection.

Car headlamps are an important safety feature. Rapid developments are expected in this area. Volvo and other companies are actively involved in developing, for example, ultraviolet light for headlamps. Things look very promising.

Automobile dynamic safety will be developed further. Optimized chassis systems will significantly improve road holding and dynamic properties of our cars.

Tyres are becoming safer. Car and tyre manufacturers cooperate with each other, looking at the overall picture: the car - the road - the driver.

Anti-lock brake systems will continue to improve. The system will become more widespread as its price decreases.
Another area in which we have to improve before the year 2000 is in the area of environmental safety.

The auto industry also has considerable experience in this area, even if the strongest critics of the automotive industry say that even today we are starting from scratch.

In the area of environmental safety, the automotive industry has, above all, concerned itself with cleansing emissions from engines.

And, there have been significant developments in this area. The cars of today, fitted with catalytic converters, release somewhere between two and eight per cent of the amount of hydrocarbons, carbon monoxide and nitrogen oxides that the cars of the 1950s did.

My own company has a strong tradition in this area. At the beginning of the 1970s we developed the Lambda Sond together with Robert Bosch and Engelhardt. The Lambda Sond controls the optimal functioning of the 3-way catalytic converter. Today, it dominates the market in exhaust emission control technology for petrol engines. It was first introduced as early as 1976 on the Californian market.

We shall not see the last of the petrol engine by the turn of the century. Instead, it will be further developed in terms of fuel consumption and emission control. But also here we need international harmonization of emission and fuel legislation.

The latest research project which we presented earlier this year is a good example; an electrically pre-heated start catalytic converter which has the potential to reduce hydrocarbon and carbon monoxide emissions during cold starts.

More and more manufacturers are now assuming responsibility for the environment.
We believe that cars play an important role for people today and that they will continue to do so in the world of tomorrow. If the automobile is to retain its standing, however, we must reduce its impact on the environment or else discard it.

The concerns of the future will not be emissions alone. The total environmental impact of the motor car during manufacture, while in use and at the time of scrapping will be questioned.

You will have a chance to hear more about the way we work with the environment from an overall perspective as part of tomorrow's conference.

I have now spoken about two areas of safety: traffic safety and environmental safety.

In the 1990's, we are going to find ourselves in situations where these two areas are more or less in conflict with each other.

The classic relationship between weight and fuel consumption is already an example of such a conflict. Improving car safety often means that the vehicle becomes heavier and fuel consumption increases. Electric cars with their heavy and bulky batteries reduce passive as well as active safety.

Questions such as these must be tackled by taking an overall view of the situation; not only by the manufacturers but by all players on the traffic stage. This means that you must help us analyse and evaluate as traffic safety specialists, what is best for the future.

For example, it has been demonstrated that methanol has advantages in terms of emissions; and we are able to manufacture methanol engines if there is a demand for them. But the human being may be more vulnerable to methanol than petrol. It is now time for others to say what they think and thereby contribute to the overall picture. The overall view is important!
In addition to safety and the environment, there is another important factor to be considered before the dawn of the next century. I now refer to the rapid development in the field of electronics.

Today's electronics are a prerequisite for, and perform basic functions in, airbags, emission control systems, brake systems, suspension systems, gearboxes etc.

Without the use of electronics, these systems would not perform well enough to fulfil legal standards.

Future developments in the field of electronics will continue to bring about improvements in these traditional areas. It will also be the foundation for improved traffic-user information and traffic control. We have only seen the beginning of electronics in the service of traffic safety.

The Prometheus and Drive Programmes are programmes specifically designed to actively work for safer cars, traffic safety and a better environment. They illustrate how the automotive industry can find solutions by itself to the problems that car traffic has created.

A good example of cooperation in the Gothenburg area is the testing ground for traffic control established by the local authorities and industry. Such initiatives are important so that we can sort out the really good ideas from those that are just highly sophisticated technology.

Another way in which car manufacturers can support traffic safety research and development is exemplified by the annual Volvo Traffic Safety Award. Five years ago, we realized that researchers and practicians had difficulties in making their solutions known to the general public. There have been six winners so far and each one has been able to disseminate ideas using the prize money. We will be hearing from this year's winner later on today.
Ladies and gentlemen, I do not doubt for a moment that we are creative and competent enough to successfully reach our goals.

There is one thing, however:

We should not be willing to accept development at a price which will transform us into the servants of excessive systems and technology — we must not lose the "human aspect" along the way.

It is essential that the debate and the decisions reached about development in the field of traffic are arrived at in collaboration with the parties concerned. I would like to stress once again that an overall view on the driver, the car, the roads and the traffic is most important, both when it comes to safety and the environment. Only then can we succeed in providing a socially acceptable automotive transport system for the future.

Thank you for your attention.
The Use of Simulation to Improve Vehicle Design

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THE USE OF SIMULATION TO IMPROVE VEHICLE DESIGN

Because of its vocation, the INRETS is led to carry out a large number of onboard measurements on vehicles running on road, track or dynamometer bench. These are related to the actual use of the vehicle (kinematics followed, consumption, trip duration and length) or to the influence of parameters on consumption (5th gear, electrical consumption, load, rolling resistance).

These experiments have taught us a great deal of things about actual kinematics representing different type of traffic (urban, road, motorway).

It was then interesting to develop a model forecasting consumption of a vehicle and conditions of use of its engine and transmission for differents types of kinematics from a congestive urban cycle to motorway cycle.

The model has been developped in FORTRAN on a SUN station and is now available for 10 types of vehicles using 4 types of internal combustion engine.

The average accuracy in matter of consumption is about 5% for ECE standardised cycle and stabilised speeds of 90 and 120 Km/h.

The informations given by the simulation about the actual use of
the engine helped us to forecast fuel consumption reduction of a parallel thermic-electric hybrid transmission. In this concept the electric motor is used for low required power motion and the internal combustion engine is actuated as soon as the power demand exceeds that of the electrical motor and 200 Kg of Pb/ac batteries showed that a reduction of about 60% in consumption is feasible in urban conditions. The consumption is then shared between fuel and electricity.

The use of another kinematics however showed that these goals could not be reached under road traffic conditions and that the balance could even be negative in motorway cycles.

The use of the model combined to the kinematics representing actual type of traffic is then very precious to study engine and transmission parameters of a vehicle all over its range of use which gives much more information than the study of standardised cycle.
THE USE OF SIMULATION TO IMPROVE VEHICLE DESIGN

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I Introduction

Because of its vocation, the INRETS is entrusted with the task of carrying out a lot of measurements about consumption and emissions, both on test bench and on road, according to standardized kinematics or in actual use.

Data collected from recordings made on vehicles under real traffic conditions (EUREV study, ref 1) have enabled the achievement of typical kinematics of use. These kinematics obtained by a data analysis from the recorded speed values are representative of a wide range of use from a congested urban to a motorway traffic (ref 2).

Therefore, it was interesting to develop a modeling of a vehicle behaviour which, associated with these kinematic data, would make it possible to obtain a great deal of valuable information contributing to a better knowledge and an improvement of the motive power unit.

The use of this model also gives accurate results about some parameters (aerodynamics, vehicle load, gear box use) which affect consumption and are thus quite interesting for performing experiments.

The program of calculation, together with its running and some of the results obtained, are dealt with in the following chapters.

With the data supplied by simulation about the use of an i.c. engine in a particular vehicle, it has been possible to highlight and assess the possible savings on the engine consumption in idle and overrun phases and the consequences of undersizing the engine on the vehicle consumption and performances. The advantage of using a parallel, thermic-electric hybrid transmission, with the result that part of consumption is transferred to electricity has also been showed.

However, the calculation carried out on various kinematics demonstrates that the potential of fuel reduction obtained with various solutions is highly connected to the vehicle use. A hybrid transmission for example will not be interesting in the case of a multi-purpose vehicle, as we will see thereafter.

II Model description

1) Principle

The principle of the SIM model consists in determining by calculation the conditions of motion of a vehicle according to a kinematics defined through successive speed values.

The program performs, at each time instant, the calculation of the conditions required for the motion, of transmission and motor operation as well as the relevant energy consumption.
The major steps of the calculation are given in figure n° 1 for a conventional transmission. The program has been designed to be modular, each elementary function being carried out by a particular sub-routine.

The SIM model has been developed in FORTRAN on a MATRA-SUN workstation, the package representing 3000 lines of program.

Fig. 1 General flow chart for a conventional transmission.

2) Hypothesis definition file

All parameters required for calculation are contained in four files which are selected at the beginning; that is to say:

a) The kinematic file contains the instantaneous speed data and possibly the gear ratio values to be used and the profile of the travelled hill or the existing wind. Kinematics can be standardized (ECE, J227 ...) or specific to the INRETS (actual use kinematics we described below). These cycles are interesting in so far as they represent different type of traffic, from the jammed urban traffic up to the motorway one. (See cycle features in Annex A). Speeds are defined in files at the rate of one value per second.

b) Aerodynamic, mass and rolling resistance elements are defined in the vehicle file. Features of more than 10 vehicles (with their transmission) are stored in the program.

c) The elements defining the motor coupling to wheels can be found in the transmission file, i.e.:
- type of transmission (thermal, electric or hybrid)
- gear reductions and efficiencies of power train elements
- curves defining gear changes for a gearbox
- for a hybrid transmission, type of electric motor and its connection to wheels.

d) The engine file contains the elements defining the engine, its inertia, its operating range as well as the consumption values, throttle opening and pollutant emissions determined on test bench. Recordings have been carried out with a pitch of 200 r.p.m. and 10 Nm, that is to say 300 to 400 points per engine. The use of engine speed and torque representation instead of speed-power lead to more accurate results, especially in low load engine operations met in urban conditions as we will see. Great care has been taken in low or nil power delivered and idle for engine parameters recording on test bed as they are particularly unsteady working conditions. An automatic procedure has been used for engine mapping to drive the engine on the test bed and to perform data acquisition (ref. 3). At the present time, six engine maps are currently available with volumetric displacements ranging from 1300 to 2000 cm³, some of them have been stretched in speed and torque in order to match different versions of the same engine. This operation enables us to cover a wider range of vehicles in good conditions of accuracy provided that the speed and volumetric ratio range are not too wide (ref. 4).

3) Calculations of loads applied

When the vehicle is moving, the influence of the environment is modeled by four loads calculated in the CALFORC sub-routine, i.e.:

a) The rolling resistance which can be expressed through a constant, or a quadratic speed function (eq 1) or the HOERNER formula (eq 2), i.e.*:

(eq 1) \[ FR = M \cdot g \cdot (0.0103 + 610^{-5} \cdot v^2) \]

(eq 2) \[ FR = M \cdot g \cdot (0.00499 + 1056 + 1.239 \cdot v^2) \cdot 10^5 \cdot P \]

The numerical values of the formula (1) correspond to a current, middle-size vehicle (800 to 900 kg). The HOERNER formula has the advantage of including the pressure of tyres; values obtained with this formula have been compared with those of other models and appear to be precisely matching (ref. 5).

b) Inertia loads which can be split up into one section due to variations in linear velocity and one section due to angular variations. If the inertia of power train elements is neglected, the last term is limited to the section due to wheels and to that caused by the engine. The angular speed of the wheels being proportional to that of the vehicle, the effect of their inertia can be calculated using the vehicle acceleration and an equivalent mass representing half the wheel mass.

On the contrary, the rotational speed of the motor is linked to the transmission use; consequently, the corresponding inertia will be taken into account, at the engine, in the form of an additional resistant torque:

So, it can be expressed: (eq 3) \[ FI = (M + 0.5 \cdot m) \]

* Meaning of parameters are given in Annex B.
c) The aerodynamic resistance load can be divided into one part corresponding to the vehicle advance (eq 4) and the other part corresponding to wind action (eq 5), i.e.:

\[ \text{eq 4 } \quad FA = 0.5 \cdot r \cdot S \cdot C_x \cdot v^2 \] in case of no wind.

\[ \text{eq 5 } \quad FA = 0.5 \cdot r \cdot S \cdot C_x \cdot Kw(z) \cdot V_r^2 \] in windy conditions

with \( V_r \) and \( Kw(z) \) velocity and yaw angle of the air seen from the car.

The coefficient of aerodynamic drag variation depending on the angle of yaw (a) corresponds to values determined by tests carried out on experimental models or in full size (ref. 6 and 7). Wind can only be defined from the front sector because information is missing on the rear aerodynamic drag of a vehicle (since the aerodynamics of vehicles is very advanced at the present time, it was thought that the use of identical aerodynamic drag values for a tail wind was not rigorous).

d) The load due to hill gradient is calculated from the hill value read in the kinematic file, i.e.:

\[ \text{eq 6 } \quad FP = M \cdot g \cdot P / 100 \]

Knowing the loads applied enables the calculation of the power necessary to the motion and, depending on its type, the determination of the phase type, driving or overrun phases.

Then the gear ratio and efficiency of the transaxle allow determining the engine speeds and the torque at the gearbox. The transaxle efficiency has been fixed constant to 95 %, which seems to be a good approach to reality (ref. 8, 9, 10).

4) Control of the gearbox

As the purpose of the modelling is not to study the influence of the driver, gear changes are automatically determined by a sub-routine, from curves defined according to the vehicle speed and engine throttle opening.

However the engine speed values defining upshifting conditions for steady state and full power operations can be fixed or modified by the user in order to determine their influence on the engine use and consumption.

In the calculation the program re-uses the ratio of the previous instant time to determine whether a change may be necessary depending on instantaneous conditions of speed and load (corresponding to a throttle opening). In case of change, an iteration is made until steady state operating conditions are achieved. Criteria for a no-change can be the time spent since the last change or an engine speed operating range to be met.

Once the ratio is determined, the program allows calculating the engine revolutions and the torque on the engine side using the corresponding efficiency and gear reduction.

Losses in the gearbox are modeled so as to reflect the portion due to frictions between gears (term \( Ro \) in eq 7) and the portion due to gears churning in the gearbox oil, i.e. (ref. 4):

\[(eq 7) \quad P_{bv} = (1 - Ro) \cdot PUI + 1,410^{-5} \cdot \text{REG}^2 \]

The \( Ro \) term is fixed for each ratio from 0,96 in first gear to 0,99 in fifth gear.

This formula reflects the degradation of the efficiency which has been observed in operation at high speed and low load.

VTI RAPPORT 362A
In the program, the time of gear ratio shift is assessed to be lower than one second, which does correspond to the values actually observed.

5) Clutch control

Before calculating engine parameters, the program must solve some situations where the engine speed is too low and thus would prohibit its operation; this is the case with startings and evolutions at very low speed met in jammed urban traffic.

Slip control is thus ensured by a sub-routine, the engine speed being all the more high that acceleration and/or hill gradient are significant. The speed values fixed have been determined so as to best reproduce actual developments.

These operating phases which are not significant in road or motorway cycles can represent up to 30% of the displacement time in jammed urban traffic.

6) Calculation of parameters of the i. e. engine

As it is indicated in figure n° 1, three operating phases can be observed on the i. e. engine operating conditions, i.e.:

a) Driving phases: At first, the program increases the torque required in order to take into account the engine inertia which is disregarded in maps achieved on bench and which is calculated from the inertia moment and the angular acceleration of the engine. The influence of this inertia is not negligible on lower gear ratio, it represents up to 5% of the consumption in urban conditions. On road and motorway, due to higher gear ratio use and lower accelerations this influence is quite negligible (less than one percent).

The engine parameters can then be calculated from the values contained in the engine file. At each calculation step, the program looks for the nearest engine speed and torque points in the four adjacent quadrants and determines the parameter value at the operation point through interpolation on the four values selected.

The parameters calculated are mainly consumption and throttle opening, or emissions of pollutants.

For carburetor engines equipped with an accelerator pump, the calculation must be modified in order to take into account the volume injected according to throttle opening.

Pump characteristics are directly measured on the carburetor. The pump has an influence of about 2 to 4% on consumption depending on the kinematics and the profile of the control cam.

b) Overrun phases: In this motion phase where the engine is not prompted, the accelerator is at rest; for injection pump motors, the corresponding consumption is nil. For carburetor engines, this has been assessed from the consumption at idle, assuming a sonic flow in the carburetor.

Since the motor bench used does not make it possible to achieve drive (Foucault current brake), emissions could not be measured during these phases and consequently the program will only be able to give emission values at stabilized speed.

c) Standstill phases: When the vehicle is at stop, engine consumption corresponds to consumption at idle available in the file of the engine map.

7) Particular case of developments at max. power

It may happen that the vehicle cannot follow the kinematics, which means that instantaneous speed and acceleration values lead to a power that the engine cannot supply, independently of the gear used. In this case, the program will, at each instant, gradually reduces the speed until feasible conditions are found again.
In this operating phase where the maximum engine power is required to be as close as possible to the kinematics, the gearbox is controlled so that gear changes occur at the maximum allowed engine speed. This configuration allows performances to be tested in acceleration and at the maximum vehicle speed. Figure 2 illustrate the method used for acceleration performances determination. The required kinematic is an envelope curve that no vehicle can follow, consequently the vehicle is driven at its maximum capacities during all the calculation. We can see on the figure the required kinematic and the modelling response for one vehicle equipped with four different types of engine.

fig. 2 Acceleration performances determination on 1000 m (1 t vehicle)

8) Results given by the SIM program

When calculations are completed, the program yields results describing all the parameters, the main ones are as follows:

a) Maximum and average powers, speeds and loads at different points of the transmission.
   Statistics about gearbox use ; times spent for each gear used .
   Distribution of energy flows with running total for the different phases (driving phase and overrun).
   The fuel consumption and its distribution per phase (standstill, driving and overrun phases).
   Emissions of pollutants for stabilized speeds.

b) In addition to data directly usable, the program collects instantaneous values of all calculation parameters for statistical or graphical processings ; i.e. :
   Development of parameters depending on time.
   Statistical distributions.
   Achievement of matrices of time spent on the various operating points.

III Validation of the results

The results obtained through calculation for ten vehicles equipped with six types of engine have been compared to official consumption values (ref. 11) and to results of performance tests from the published data.

As far as consumption is concerned, the average accuracy is about 5 % for the ECE standardized cycle and about 6 % for stabilized speeds of 90 and 120 km/h : these values are comparables to those found in litterature (ref. 12, 13, 14).
It should be noted that the accuracy achieved for consumption is difficult to assess in so far as results obtained on several identical vehicles, during the same test, may vary significantly. By comparison, the error on a modelling could be reduced to 2% by using the same engine to carry out the tests on vehicles and the required engine maps (ref. 15).

For vehicle performances determination in maximum speed and acceleration the average accuracy is about 4% with a slight tendency of undersizing performances for the calculation.

IV Application - knowledge of actual vehicle and engine use

In order to highlight the actual vehicle use in various conditions we made calculations on the 10 types of INRETS kinematics.

Main results are listed below for a new design middle size vehicle*, concerning the applied loads, the engine use, consumption and efficiency.

1) Energy flux sharing.

To precise the relative influence of each parameter it is interesting to know the distribution of the energy flux necessary to motion in driving phase according to the vehicle use. The results are given in figure 3 where the kinematics are classified according to the average displacement speed. Above each column the average acceleration and speed of the driving phases are indicated.

Fig. 3 Energy flux in driving phases (vehicle n° 3).

It should be noted that the energy flux slightly increases with the kinematic average displacement speed in a non monotonous way; this is due to the evolution of the relatives parts of the flux corresponding to the 3 loads applied**.

The rolling resistance expressed as a constant and a low coefficient function of squared speed slightly increase with speed, it represents from 23 to 28% of the total.

The aerodynamic load expressed as a squared function of the speed is quite negligible in urban use and increases extremely rapidly to take the major part on motorway (from 50 to 60%).

---

* See characteristic of vehicle n° 3 in annex C
** The calculation is made with no wind or slope.
The inertia load is a function of the acceleration of a given vehicle which can significantly vary from a kinematic to another one. Its relative part is very important in jammed urban condition (about 75%) due to the absence of aerodynamic load. This inertia load remains important in fluid urban and low speed road conditions due to higher accelerations (up to 78%) but is very small in high speed road and motorway conditions due to lower accelerations and high aerodynamic loads.

We can notice that the ECE cycle which is close to fluid urban kinematic N° 3 as regards average displacement speed is extremely different in average acceleration from the actual use kinematic. Consequently the corresponding energy flux is smaller.

So we can say that for the energy necessary to motion:
- The influence of rolling resistance does not significantly depends on the kinematic.
- The influence of aerodynamics equals zero in urban conditions, is noticeable on road and extremely important on motorway.
- The influence of the vehicle weight will be extremely important in urban conditions, significant on road but not on motorway.

These remarks are relative to the energy necessary to motion but we will see that for an i. e. engine we will not be able to extrapolate it to the fuel consumption because of the importance of idling and overrun phases.

2) Engine operating conditions

The calculation enables us to determine at each instant the engine speed and load which constitute the two first axes of the figures n° 4a to 4d. The third axis represents the time spent by the engine in the corresponding situation.

Fig. 4 Engine operating conditions (vehicle n° 3)

a : jammed urban  
b : fluid urban
As we can see the jammed urban kinematic is very unfavorable for the engine which is used at a very low load, speed and efficiency area (average efficiency in driving phases 12 %).

For the fluid urban and road type kinematics we can see that the surface covered is wider and located in better efficiency areas (average efficiency respectively 16 % and 26 %). This evolution is due to a wider range in speed and acceleration values for these kinematics.

For the motorway type kinematic the surface covered is relatively small due to the important time spent in quasi stabilized speed, but is located in a relatively better efficiency area because of important speed values leading to high engine speed and load (average efficiency 27 %).

3) Engine consumption and efficiency

The engine consumption can be calculated for various types of use according to the different phases of motion (standstill, driving and overrun phases). The figure n° 5 shows the variations of consumption and its three constituting parts according to the different types of vehicle use.

Fig. 5 Engine consumption
As we can see the idling part is very important in jammed urban conditions (up to 35% of the total) due to the significant time spent at standstill\(^1\) and the relatively low consumption values in displacement (extremely low speeds).

The evolution of these two parameters for the others kinematics leads to a rapid decrease of the idling consumption from about 10% in fluid urban conditions to 4% on road and quite zero on motorway.

It can be noticed that the ECE cycle has an important idle part consumption due to a greater time spent at standstill compared to the INRETS kinematics (33% of the total time for no more than 14% in fluid urban No 3).

At the end of the calculation it is then possible to compare the mechanical energy produced by the engine to the energy contained in the fuel consumed for the whole kinematic or for the driving phase only, and to deduce corresponding efficiency values (given in the hereabove section).

V. Undersizing engine effects

As mentioned above in chapter IV-2, engine operating conditions are not good in urban cases since the engine is used at low load, far from its better efficiency values. Therefore in order to get engine operating and best efficiency area closer we considered a vehicle with undersized engine and calculate its consumption and performances.

To determine the effects of engine undersizing, calculations were performed on 4 types of vehicle with load ranging from 740 to 1170 kg equipped with 4 types of engine\(^2\) from 34 to 74 kW.

In order to cover a wide range of situations we mixed up the vehicle use (kinematic), the vehicle type and the engine\(^3\). The nine possibilities corresponding to 4 vehicles with specific power from 67 to 29 kW/t are listed on Figure n° 6.

![Fig. 6 Description of vehicle simulated.](image)

<table>
<thead>
<tr>
<th>Engine n°</th>
<th>Engine power (Kw)</th>
<th>Simulated case n°</th>
<th>Specific power (Kw/t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>34</td>
<td>13</td>
<td>29</td>
</tr>
<tr>
<td>2</td>
<td>58</td>
<td>12</td>
<td>49</td>
</tr>
<tr>
<td>3</td>
<td>65</td>
<td>11</td>
<td>55</td>
</tr>
<tr>
<td>4</td>
<td>74</td>
<td>1</td>
<td>63</td>
</tr>
</tbody>
</table>

Vehicle n° 1 mass 1170 Kg

Vehicle n° 2 mass 970 Kg

Vehicle n° 3 mass 940 Kg

Vehicle n° 4 mass 740 Kg

1) Vehicle performances

Knowing these hypotheses, we can then determine the performances of the vehicle. To express these ones we choose the maximum vehicle speed and the required distance for truck overtaking\(^4\)

---

\(^1\) See kinematics characteristics in annex A

\(^2\) All are i.c. carburated engines

\(^3\) Each engine is considered with its own transmission (gear ratio and shifting curves)

\(^4\) In this case the vehicle is driven at it's maximum capacities to overtake a truck, starting from the same speed (80 km/h) in this example.
The influence of engine capacities are given in figures n° 7 a and b where maximum speed and overtaking distance are expressed according to vehicle specific power.

Fig. 7 Vehicle performances.

a: Maximum speed  
b: overtaking distance

2) Engine operating conditions and consumption

The first consequence of engine down sizing will be to reduce the distance between the operating points surface and the best engine efficiency area. Consequently the engine will operate with a better efficiency giving a reduction in driving phases consumption.

As we can see on figure n° 8 the gain will be greater for the worst operating point efficiency met in urban conditions than for road or motorway use where the efficiency were better for the conventional vehicle.

Fig. 8 Engine efficiency variations.

The second consequence will be a reduction in idle and overrun, consumption with the decrease of the engine displacement. For the above considered i.c. engine the idle consumption variations are up to 33 % between the two extremes (0,7 and 0,5 Kg/h). The effect of this reduction will be more noticeable in jammed urban conditions where, as we already said, the idle consumption takes the most significant part.
The global effect on consumption of engine modifying characteristic is shown of figure n° 9. We can verify that, the most important consumption reduction is obtained in jammed urban conditions (up to 40 %).

As we said above fuel savings will be smaller in fluid urban conditions (20 to 28 %), on road (15 % to 20 %) and will be relatively low on motorway (about 12 %).

Fig. 9 Vehicle consumption reduction.

An another point to note is that the main gain is obtained in the first two steps, the third one being extremely stringent regarding the vehicle performances with no significant reduction in fuel consumption (except fluid urban conditions).

The reduction of engine capacities will not affect the possibilities of the vehicle to meet the kinematic requirement in urban use, but on road and motorway where the required power is higher, the calculation shows that it will not be the case. In the most unfavorable case (n° 13 in fig. 6) up to 8 % of the displacement time will be performed at a speed lower than the required one (respectively 4 and 3 % in cases n° 22 and 31). In such cases, the simulated vehicle will then not be able to meet the actual use kinematic acceleration requirements.

3) Conclusion

The possibility of an engine power reduction and the consequences on the vehicle performances and consumption were studied. We will now see what is reasonably possible to do, considering that the vehicle has to be driven safely.

- Specific power under 40 kW/t (cases n° 13, 22, 31).
These solutions are interesting considering the high reduction in fuel consumption, but the vehicle performances decrease is important as compared to the conventional vehicle (case n° 1, 2, 3).

<table>
<thead>
<tr>
<th>Case n° 13</th>
<th>Case n° 22</th>
<th>Case n° 31</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel consumption reduction JU</td>
<td>- 38 %</td>
<td>- 27 %</td>
</tr>
<tr>
<td>Fuel consumption reduction FU</td>
<td>- 22 to 28 %</td>
<td>- 22 to 25 %</td>
</tr>
<tr>
<td>Fuel consumption reduction R</td>
<td>- 16 to 20 %</td>
<td>- 15 %</td>
</tr>
<tr>
<td>Fuel consumption reduction M</td>
<td>- 12 %</td>
<td>- 13 %</td>
</tr>
<tr>
<td>Overtaking distance increase</td>
<td>+ 57 %</td>
<td>+ 41 %</td>
</tr>
<tr>
<td>Maximum speed decrease</td>
<td>- 24 %</td>
<td>- 23 %</td>
</tr>
</tbody>
</table>
In these 3 cases vehicles performances are significantly inferior to those of vehicle 4 which constitutes a minimum in our hypothesis for a multi-purpose use vehicle to be driven safely.

These solutions are too excessive and therefore cannot be selected for private cars.

-Specific power between 50 and 60 kW/t (cases n° 11, 12 and 21).

These solutions correspond to a vehicle equipped with an engine one size smaller (n° 11 and 21) or two sizes for case n° 12, the figures are then*:

<table>
<thead>
<tr>
<th></th>
<th>Case n° 11</th>
<th>Case n° 12</th>
<th>Case n° 21</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel consumption reduction JU</td>
<td>- 18 %</td>
<td>- 26 %</td>
<td>- 13 %</td>
</tr>
<tr>
<td>Fuel consumption reduction FU</td>
<td>- 7 to 10 %</td>
<td>- 18 to 23 %</td>
<td>- 17 %</td>
</tr>
<tr>
<td>Fuel consumption reduction R</td>
<td>- 3 to 6 %</td>
<td>- 12 to 15 %</td>
<td>- 10 %</td>
</tr>
<tr>
<td>Fuel consumption reduction M</td>
<td>-2 %</td>
<td>-10 %</td>
<td>-7 %</td>
</tr>
<tr>
<td>Overtaking distance increase</td>
<td>+ 13 %</td>
<td>+ 16 %</td>
<td>+ 5 %</td>
</tr>
<tr>
<td>Maximum speed decrease</td>
<td>- 6 %</td>
<td>- 7 %</td>
<td>- 4 %</td>
</tr>
</tbody>
</table>

In these cases, vehicle performances are not too reduced as compared to the original vehicle, especially for solution 11 and 21 where they are quite equal to those of vehicle 3 (performance reduction of less than 5 %).

So a realistic solution for vehicle 1 and 2 could be to use an engine one size smaller (specific power of 55 to 59 kW/t) allowing a significant reduction in fuel consumption for multi purpose use with a slight decrease in performances.

The use of an automatic gear box will avoid engine operating problem that could be met with undersized engine.

This solution could be valuable provided that the vehicle has enough power to be driven safely among the traffic, but not more.

In these cases, the calculation shows that engine power is sufficient to meet the kinematic requirements for the whole use.

**VI Hybrid transmission**

1) Introduction

Another way to improve engine operating conditions and then consumption and emissions is to avoid engine operating in unfavorable efficiency areas, encountered in low load part of the diagramme where pumping and mechanical losses are important.

This can be done using another power source which will hold the low motion power instead of the i.c. engine in a hybrid parallel thermic electric transmission.

If we take into account the significant actual trend towards increasing the amount of vehicle on board electric consumers with electric generator power reaching or exceeding the kilowatt we can imagine this second source as an electric one.

The vehicle could then be equipped with a high power electric system ensuring the on-board current generation, low power driving phases and the starting up of the i.c. engine since this one will only be run when its power is needed.

It will then be possible to cut down idle, and overrun consumption and a part of driving phases consumption depending on the electric motor maximum power.

* in all these cases the simulated vehicle is able to follow 100 % of the actual use kinematic
The calculation will enable us to determine the potential fuel consumption reduction and the associated electric consumption due to the presence of the second power source.

2) Electric chain specifications

The electric motor maximum power will determine the importance of the energy sharing between the two chains, and then their consumption.

Figure n° 10 allows us to estimate the correspondence between the electric motor power and the driving phases consumption cut due to its presence according to the vehicle use.

Fig. 10 Driving phases consumption reduction.

The curves have been drawn up by sharing the engine consumption according to the power delivered. Each curve represents the cumulative percentage of consumption obtained under the corresponding maximum power, 100 % being reached for the maximum engine power in the kinematic.

As we can see a relatively low electric power is enough to cover all the needs in jammed urban conditions (6 Kw correspond to a cut of 100 % in driving phases consumption) but for the other kinematics where the required motion power becomes higher a great electric power will be necessary to give a significant cut in engine consumption (a 20 Kw electric motor will not cover more than 78 % of driving phases consumption on motorway).

The selection of the electric motor power will be made considering the following points.
- One of the advantages of a hybrid transmission is the possibility of using the vehicle in an all electric mode in city center (corresponding to jammed urban kinematics) with no pollutant emissions. This will give us the minimum electric power, about 6 Kw in the example given in figure n° 10.
- The hybrid vehicle must be able to cover a sufficient distance in urban use, from 40 to 60 Km, using its own battery capacity. We will see in the following chapter that this condition will limitate the electric motor power.

3) Hybrid vehicle simulation

The calculation has been carried out with a transmission file including the characteristics of a D.C., separately excited electric motor (ref. 16), the efficiency map being normalized to allow variations in the engine speed operating range and power. The features of the thyristor control are expressed in the form of an efficiency depending on the voltage delivered at the motor armature (ref. 16).
For this type of operation, the electric motor is used up to its full capacity during driving phases and in recovery in overrun phases. The i.c. engine is actuated as soon as the required power exceeds that of the electrical motor, and is stopped out of these phases.

The results obtained on consumption for a middle size vehicle (n° 2 in annex C) are listed in figure n° 11 for the whole kinematics and several electric powers. The gain in fuel consumption is the result of idle and overrun cut and sharing between the two sources as we can see below.

![Fig. 11 Overall gain in consumption.](image)

The vehicle mass has been increased to take into account 200 Kg of lead-acid battery pack and 60 Kg of electric motor and control. The transmission efficiency has also been decreased by 5% considering the connection of the two chains to the wheels.

As we said, the consumption can be nil in jammed urban conditions with up to 7 Kw electric motor* and extremely reduced in fluid urban conditions, from 15 to 73%. But on road the results can vary from 10% lower to 1.5% higher than those of the reference vehicle, the fuel reduction being higher for great electric motor power. On motorway the transmission is unfavorable in any case with results from 2% to 8% greater than the reference ones.

This situation is the result of the decrease in fuel reduction potential for idle, overrun phases and sharing with low power electric motor.

Therefore the effects of vehicle mass increase and transmission efficiency decrease will not be balanced by the fuel reduction, which will yield a higher consumption.

Concerning the range, the 7 Kw electric motor will enable the vehicle to cover from 50 to 70 Km in fluid urban use (n° 1 to 3) with 200 Kg of lead-acid batteries. The 9 Kw motor which gives better results will not allow the vehicle to be provided with a sufficient range for a proper operation (comparatively 35 to 50 Km).

So the solution could be to associate a 7 Kw electric motor in parallel to the 65 Kw engine. The vehicle will then be drivable in all electric mode in city center (corresponding to jammed urban conditions) with a range of about 30 Km.

In fluid urban conditions the fuel consumption reduction will range from 40 to 70% with an electric consumption from 8 to 12 Kwh/100 Km leading to an operating range of 50 to 70 Km.

* The increase of 1 kW compared to the fig. 10 is due to the influence of the electric chain (mass and transmission efficiency).
Besides of these conditions the transmission will not be worth on road where the fuel reduction will be too low (from 10 to 13 %) and on motorway with an increase in consumption (from 2 to 5 %).

The performances of the vehicle will be reduced by 16 % for overtaking distance and by 4 % for maximum speed as a result of increase in load due to the electric chain.

Remark : The combination of the two solutions we have seen in chapter V and VI, under sizing engine plus a hybrid transmission will lead to a too low specific power with an excessive reduction in performances (for the vehicle simulated this one would be 47 Kw/t).

VII Conclusion

This paper has described the development of the SIM program, its main functions and the results given by said program regarding the use of the i. c. engine and transmission. The global accuracy achieved is about 4 to 5 % in consumption and 4 % for the performances of simulated vehicles.

Data supplied by the program about the use of the engine allowed us to determine potential consumption reduction by under sizing the engine or using a parallel thermic electric hybrid transmission.

We observed that on two types of large and middle size vehicles it was possible to use an engine one size smaller (cases n° 11 and 21) which will give significant fuel reduction in urban use (from 7 to 18 %), on road (3 to 10 %) and a low reduction on motorway (2 to 7 %); the vehicle performances being decreased from 4 to 6 % for maximum speed and 5 to 13 % for overtaking performances.

We also saw that it was very penalizing for vehicle performances to reduce the engine size below 50 Kw/t for large or middle size vehicles.

For parallel thermic-electric hybrid transmission the calculation showed that interesting results could be obtained in urban use with a 7 Kw electric motor on a 65 Kw i. c. engine middle size vehicle i. e.:

- The vehicle can be driven in full electric mode in city center with no pollutant emissions with a range of 25 to 30 Km.
- The fuel consumption reduction in fluid urban use ranges from 40 to 70 % with a transfert on electricity (battery electric consumption from 8 to 12 Kwh/100 Km allowing 50 to 70 Km operating range).

These results are close to those found by Volkswagen on their Golf thermic electric prototype (ref. 17).

The simulation, however, has demonstrated that these goals could only be reached under urban conditions and that the balance could be negative in road or motorway cycle.

The modellisation is precious to know the different energy flux, the engine operating conditions and consumption and to determine possible fuel consumption reduction, but this one cannot be used alone and experimentations will still be necessary to validate the model.
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VTI RAPPORT 362A
## Annex A

INRETS and ECE cycles features

<table>
<thead>
<tr>
<th>Type of kinematic</th>
<th>Duration sec.</th>
<th>Duration of displac. sec.</th>
<th>Lenght km</th>
<th>Average speed Km/h</th>
<th>Average speed of displac. Km/h</th>
<th>Maximum speed Km/h</th>
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<tr>
<td>Jammed urban 1</td>
<td>805</td>
<td>524</td>
<td>0.82</td>
<td>3.7</td>
<td>5.6</td>
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<td>811</td>
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<td>7.3</td>
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Annex B

Parameters definition

M  Total mass of vehicle (Kg)
g  Acceleration due to gravity (m/s²)
V  Vehicle velocity (km/h)
v  Vehicle velocity (m/s)
P  Pressure of tyres (bar)
Fi  Inertia load (Nm)
m  Wheel mass (kg)
acc  Vehicle acceleration (m/s²)
FA1  Aerodynamic resistance due to vehicle displacement (Nm)
FA2  Aerodynamic resistance due to wind (Nm)
r  Air volume mass (kg/m³)
S  Vehicle frontal surface (m²)
Cx  Vehicle aerodynamic coefficient
Kcx  Coefficient of Cx variation according to angle of yaw
a  Wind angle of yaw measured from the longitudinal axis (degree)
Vv  Wind velocity (m/s)
FP  Load due hill gradient (Nm)
P  Hill gradient (%) 
Pbv  Losses in gearbox (KW)
PUi  Power transmitted by the gearbox (KW)
Ro  Efficiency corresponding to friction losses
REG  Gearbox revolutions (r.p.m.)

Annex C

Hypothesis vehicle features

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Vehicle Development and Road Safety

Christa Michalik
Dr
Austrian Road Safety Board
Institute of Traffic Education
Austria
(not attending the conference)
Abstract of proposed paper for the
International Conference in Gothenburg,
Sweden (Sept. 26-28, 1990)

VEHICLE DEVELOPMENT AND ROAD SAFETY

Technology in its original sense was intended to make life easier for man. It was and is developed by man and for man. One result of technical developments is the vehicle - at present considerably attacked as killer of the environment, as killer of towns and villages, but much more infrequently as killer of men.

Man believes in technology. Technicians believe to make life easier for man with their developments - also regarding road traffic. However, as far as vehicle development and road safety are concerned, the efficiency of these efforts must be doubted. Because it is still man who uses or misuses technology when driving; because the strained relationship between technology and man is not or hardly considered in many developments. From these considerations the following questions can be deduced:

- To what extent can vehicle technology influence road safety?
- To what extent does today's vehicle development correspond with the needs of man?
- To what extent can man's behavior be influenced into a positive or negative direction by means of technology?
- Which factors promote or inhibit the positive use of technical vehicle developments and thus have a positive effect on road safety?

These questions are answered and approaches for solutions are presented from the point of view of human science.
Man believes in technology. Engineers believe to make life easier for man with their developments - this is not only true for road traffic but for all fields of life.

As far as motor vehicles are concerned that means: There can be no doubt that numerous technical developments have been made during the past 25 years to improve vehicle safety. Most of them are based on detailed analyses of road accidents, but also on investigations of ergonomic, kinetic, and biomechanical conditions.

Under the aspect "technology as a means to protect man" the so-called "passive safety" in vehicle construction shows considerable successes. The wide range of positive results does not only include the development of laminated glass, of energy absorption zones, the construction of seat belts, but also the development of a vehicle design that reduces possible injuries in case of collisions with pedestrians. The success of vehicle development regarding the minimization of the consequences of accidents have to be acknowledged. As an example the obligatory wearing of seat belts can be mentioned: As of course the obligatory wearing of seat belts did not have an influence on the number of accidents, it had a positive effect on the number of injured persons as well as on the number of fatalities in Austria. That means that - like in many other countries too - the improvements resulted in a reduction of the severity of accidents.

Unfortunately quite the opposite is true for technical improvements in the field of so-called "active safety" which have no or only marginal positive effects on road safety. Improvements like for example the development and use of spikes, of four-wheel-drive, of ABS, to name only a few, resulted in a more sportive driving style and higher driving speeds and thus in an increase in the severity of accidents. That means that the safety intended and provided by engineers was more than compensated by man's driving behavior.

What is today's trend in vehicle development? Here we have to differentiate between cars offered nowadays and those which are in development now and therefore will be available in about 10 years.
Let's consider the present state from a critical point of view: Never before more powerful cars have been offered - 300 HP and more. Never before vehicles driving so fast - 250 km/h and more - have been offered. This development has to be seen on a background of maximum speed limits all over Europe. Hardly ever before vehicles were provided with so much luxury as they are now. Never before the car was so much of a toy and playmate, object of prestige and pleasure. Is it a kind of madness of technology seeking for its limits? Higher speeds do demand control of these speeds - the looser very often is man.

Why is speed so fascinating?
As long as we can think back man has been dreaming to increase his own speed - let's just think of the story where the hero wears "seven mile boots". Speed was and is equalized with freedom and the handling of speed is experienced as one's own free decision. But even after more than 100 years of companionship with the automobile man has not yet developed any sense for speed. He has to use auxiliary means to compensate this deficiency by his kinesthetic perceptions, noise, peripheral stimuli on the retina, etc. This allows him - in a very limited way - to handle higher speeds.

The first means of transportation of man was the horse which gave very direct feedback. When driving on nowadays broad roads in our modern silent cars with only very little feedback it is extremely difficult for man to handle speeds. But man is not conscious of this danger because driving at high speeds does not demand any special skills. Only in critical situations where it would be necessary to stop or turn aside quickly he realizes that he has no command over the car - but then it is often too late.

Considering all these aspects it is strange to observe that the modern cars get more and more silent and so more and more increase this dangerous subjective feeling of safety. Without checking the speedometer the driver can estimate the speed driven not even approximately. The automobile producers argument that the consumer demands this comfort. Their point of view is that man is a "reasonable" creature. Therefore vehicles with maximum speed that can never of hardly ever be driven on normal roads are offered - the temptation offers itself - why should man not submit to it?

More and more technical equipment is offered which tempts man to feel safe and that induces him to take higher risks. Instead of using the technical developments as a safety reserve for critical situations man makes full use of the technical
possibilities. They increase the subjective feeling of safety but unfortunately also the objective risk. This is in contrast to the intentions of engineers who want to provide more safety.

Advertising, too, is an important influencing factor in the above mentioned direction. It is taken very seriously by most consumers who lack the technical knowledge to evaluate the truthfulness of the message. Let me give a concrete example: Most consumers believe that ABS reduces the stopping distance considerably which in fact is not always true. Its real advantage is that the driver can steer the vehicle while braking - but that demands practice. If the driver is not trained accordingly he will not be able to make use of this technical advantage in critical situations. What remains is that the driver takes higher risks due to his belief in misleading advertising messages. So it is not surprising that certain types of accidents increase with ABS.

Another hypothesis to explain the fascination of speed to man could be found in the following ideas: In our high-technology environment it is almost impossible for man to witness the development of a product and thus to get the feeling he has contributed his share. An extreme example in this connexion is working on the assembly line without any feedback and without any opportunity to see the final product and so experience the relationship between cause and effect. When driving a vehicle the "effect" of an action can always be felt and experienced immediately: when breaking, accelerating, driving on winding roads, etc. This is certainly one of the reasons for the strong emotional relationship of many human beings to their car.

Summarizing it can be stated that nothing is perfect - neither technology nor man. After all he is not as reasonable as it is argued. He is a human being with a certain relatively well known "construction" - to use a technical term - with certain deficiencies and needs. Unfortunately many of the vehicles offered today do not take into account man's possibilities and limits. As long as increased traffic volume is used as a justification for stagnating accident data, and as long as this is socially and politically accepted or even appreciated as "success" there is not much hope for changes - at least for the moment.

Let's have an outlook to the future, to the developments in elaboration for tomorrow and after tomorrow the following scenario is not too far away:
The realizations of modern microelectronics, information processing, and telecommunication are utilized in vehicle construction. For the first time the vehicle is not considered isolated but is considered as part of a new and homogeneous traffic concept. Intelligent cars in wireless communication with intelligent traffic signs and a congestion warning system - but what about the driver? Does such a development modify the requirements to the driver or is he rendered unnecessary in the end - a passive user instead of an active participant?

Even in the age of "intelligent road traffic" the driver will still be responsible for his safety and the safety of the other road users. He will have to act responsibly because even the best technology cannot grant total road safety. Lots of considerations will be necessary to decide what kinds of information shall be offered in which form in order to be successful. They have to be accepted by man without overcharging him. Therefore additional measures which demonstrate the advantages of these new technologies to man should be elaborated parallel. Acceptance by man is not to be expected automatically. Let's think of a simple example: Many drivers refuse to buy or drive a car with automatic gear-shift because it is not suitable for a sportive driving style. The advantages of technology are not valued at all in this case.

Discussing the future of the automobile is certainly not possible without discussing its function in everyday life. If the use of the car is not defined in advance the future car won't as little meet the requirements as nowadays cars do - namely to serve man, his health (safety), and the environment. I wonder whether these considerations have been taken into account in connexion with "Prometheus".

Returning to the present time it has to be stated that in contrast to vehicle development in road construction and road equipment many of the above mentioned critical considerations have already been taken into account. For example it is scientifically proven that broad roads through villages are a temptation to drive fast to most of the drivers. Road traffic planners do now help the drivers by means of reorganizing these types of roads. As far as automobiles are concerned the reasons for speeding are well known, too. Nevertheless, "maximum speeds" are still a very important factor in automobile advertising and there is no hope for a similar development in cars.

As we all know from accident analyses road accidents do always have a component of speed and it certainly is no coincidence that more powerful cars which mostly have a higher safety standard, too, are more
often involved in accidents than less powerful vehicles.

To sum up it has to be stated that vehicle technology has a strong influence on road safety - whether man uses or misuses the technology when driving.

Some investigations showed that the modern automobiles that are provided with all kinds of safety equipment only provoke speedy, risky, and careless driving because they increase the drivers' subjective feeling of safety. Is it just coincidence that the average speed driven in Austria increased by approximately 10 km/h - the maximum speeds increased by 30 km/h within one year (1988) - and hand in hand with these facts the severity of accidents on motorways increased as well as the number and severity of accidents involving pedestrians.

Obviously the relation between vehicle development and efforts for higher road safety is quite strained. Considering the following ideas and proposals it should be possible to counteract the above described trend and enhance road safety in a relatively economic and fast way:

Our knowledge of the human being with all his possibilities and limits as far as his behavior in road traffic is concerned is quite comprehensive. As man is the user and driver of vehicles, efforts should not mainly concentrate on appealing his emotions but rather on informing him about construction details which are orientated at the well known limits of man. To produce what is required by the customers is one thing, to raise the demand previously is another thing. The old question "what was first - the hen or the egg" should not be valid any more.

In coordination with technical developments corresponding research is of high importance. This research should not only be restricted to biomechanical investigations, function checks, ergonomics, etc. but investigate their influences and effects on man's behavior in road traffic. Very important questions that should always be checked are: How does man handle a new technical development - does he use it reasonably or does he misuse it according to safety standards? If the latter is true the development would have to be revised or stopped.

A better future for road traffic can only be accomplished if the tasks and the function of the vehicle are redefined and the results are taken into
account for development (e.g. individual traffic versus public transportation systems, combination of different means of transportation, environmental problems and citizen's initiatives against road construction, reasonable selection of the means of transportation, etc.).

The human being and his interaction with the traffic system has to be considered from a holistic point of view. In the long run it cannot and should not be man who has to adjust to technology to survive. It is high time that technology is adapted to man's requirements, that advertising messages rouse a consciousness of safety, and that the strategy of vehicle industry to produce mainly what can be sold easily is stopped. Technology should contribute to humanize road traffic by producing and offering only products which are an advantage for people. Today's vehicles are orientated at the buyer's desires. What we need are vehicles that are orientated at man's actual requirements. Main emphasis in all new developments should not be put on what is possible from the point of view of technology but what is useful for man - useful from the point of view of accident prevention.

As already mentioned there has been done a lot in the field of passive safety during the past years and there are only few possibilities left - now it is high time to concentrate all our efforts on the increase of active safety. The automobile shall not be condemned - it has its place in our life. But it has to be adjusted to our requirements instead of being a permanent temptation to go beyond our limits. That means that after the reorganization of roads (e.g. lane substruction, building bottlenecks into broad roads through villages, but also other measures which prevent drivers from speeding) a similar development will have to take place in vehicles by constructing cars which give more feedback to the driver.

Finally three demands shall be defined and addressed to those who are working on vehicle development. The goal should always be to construct vehicles which help man to cope with road traffic safely and support well adjusted behavior.

Therefore previous to and/or during each new development the following questions should be put using adequate methods and answered:

- Does the technical element or new development in question increase man's subjective feeling of safety in a higher degree than the objective safety? If this question has to be answered with "yes" the development counteracts road safety.
Is the technical development constructed in a way that man is not able to perceive the actual risk due to a lack of feedback on objective risks? If this question has to be answered with "yes" the development counteracts road safety.

Does the construction development extend the freedom of action for the driver in order to support man's play instinct? If this question has to be answered with "yes" the development counteracts road safety.

Future will tell whether man is reasonable enough to develop technologies which meet man's requirements and consider the already known interactions of the whole system man - automobile - and road with view to a more human and healthy road traffic system. To reach this goal we of course need much more research investigating man's behavioral adaptation to technical innovations. However, we do know already enough to see the dangers and to counteract them. Now!
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The Role of the Motor Vehicle in Traffic Engineering of the Future

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THE ROLE OF THE MOTOR VEHICLE IN TRAFFIC ENGINEERING OF THE FUTURE

Prof. Dr.-Ing. Christian Voy,
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ABSTRACT

The automobile has been around for a hundred years. In that time it has profoundly influenced the development of our society, its economic and ecological systems, the working environment and the infrastructures. Thus for example the motor vehicle and the international road network have brought us a mobility hitherto unknown in the history of mankind. This shapes our personal life and the economy of our country in a beneficial way.

Forecasting the future of the motor vehicle is naturally a tricky business. There can be no guarantees. It does however seem certain that the automobile will still be the most important means of transport for people and goods in the year 2000. It is predicted that by the turn of the millennium two-thirds of the expected increase in the traffic will devolve upon the individual passenger car. The expected growth in public road and personnel transport will be almost exclusively in favour of the omnibus. This means ultimately that considerably more than 90% of future traffic will be handled by the motor vehicle.

The constantly increasing volume of traffic and the equally constant development of technology have led however not only to an augmentation of the social good; they also bring about significant negative effects, above all in the areas of safety and environmental considerations.

As a result the state of development of the traffic system on the one hand and a marked sensitisation to the negative effects of road traffic on the other have altered the objectives and activities in the road traffic sector.
Concepts and solutions must therefore be worked out which make individual, commercial and public road transport throughout Europe safer, more economical, more environment-friendly, more efficient, and less stressful for the driver.
THE ROLE OF THE MOTOR VEHICLE IN TRAFFIC ENGINEERING OF THE FUTURE

Prof. Dr.-Ing. Christian Voy,
DAUG Deutsche Automobilgesellschaft, Brunswick

THE PROBLEMS

The automobile has been around for a hundred years. In that time it has profoundly influenced the development of our society, its economic and ecological systems, the working environment and the infrastructures. Thus for example the motor vehicle and the international road network have brought us a mobility hitherto unknown in the history of mankind. This shapes our personal life and the economy of our country in a beneficial way.

Forecasting the future of the motor vehicle is naturally a tricky business. There can be no guarantees. It does however seem certain that the automobile will still be the most important means of transport for people and goods in the year 2000 (Fig. 1). It is predicted that by the turn of the millenium two-thirds of the expected increase
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As a result the state of development of the traffic system on the one hand and a marked sensitisation to the negative effects of road traffic on the other have altered the objectives and activities in the road traffic sector.

It will therefore not be sufficient, for the optimisation of the integrated systems of people/vehicles/goods, to rely on the improvement of the single component of vehicles for example or traffic legislation. In future it will rather be a matter of emphasising optimisation of the entire combination. This means that attention will be directed less to the technology of the individual motor vehicle than to the traffic system as a whole with all its technical, political, economic, ecological and social aspects.
Concepts and solutions must therefore be worked out which make individual, commercial and public road transport throughout Europe safer, more economical, more environment-friendly, more efficient, and less stressful for the driver.

SAFETY

This means, firstly, through more information, bringing about better cooperation between road users and thus avoiding accidents. The point is

- to recognise critical traffic situations immediately they start to emerge,

- to actively support the driver in dangerous situations through machine intelligence,

- to design the interplay of driver and vehicle in such a way that the driver can be unequivocally responsible for safety.

ECONOMY

Secondly, the energy-wasting elements in today's traffic must be reduced. How often do we have to stop at road junctions, traffic lights or halt signs when there is no traffic to stop for? For a heavy truck every re-start
means another litre of fuel consumed, and the production of a corresponding quantity of CO$_2$. Communication systems between vehicles and between vehicle and road installations could help reduce the number of unnecessary braking and accelerating operations. The reduction of time spent searching for a parking space, and of circuitous routes, also increases the economy of traffic.

EFFICIENCY

Thirdly, traffic must be made more fluid through better organisation. The task is to find for Europe as a whole the best possible distribution of technology between vehicle and road installations and to develop an overall plan for the introduction of these systems.

ENVIRONMENTAL ACCEPTABILITY

Fourthly, every improvement in traffic organisation with a better utilisation of the existing road network will contribute to reducing the requirement for new roads. Equally, all measures for harmonising traffic flow and avoiding unnecessary traffic will serve to increase environmental acceptability.

COMFORT

Fifthly, we do not wish to sacrifice the pleasure of driving and the character of individual transportation with people as the central component. However, situations leading to high stress must be avoided.
INFORMATION/COMMUNICATION

Let me now present some concrete approaches to the solutions I have sketched in general terms.

The least interference with existing technology will result from improvement of driver information in the closed loop system of traffic bulletins/road/driver/vehicle (Fig. 2). Today the only sensor on the vehicle which is directed outwards, apart from the car telephone, is the radio aerial. It provides the driver with an overall picture of traffic density (jams), accidents and road conditions in ever-improving quality (ARI, ARIAM, RDS). The traffic information systems affects choice of route and warns of particular events.

An obvious, and with the constantly increasing amount of information (e.g. Ruhr region) necessary improvement is the automatic selection of really relevant traffic bulletins. A condition of this is however constant position finding in the vehicle. The VW research division offers a process using the existing RDS signals themselves for position finding. (Fig. 3).

An advantage of this process is that on the one hand the entire necessary infrastructure is already there, which means extremely low start-up costs for the system, and on the other this is an automatic location method needing no kind of position input at the start of the journey.
The position-finding system in the vehicle is an integral part of the RDS car radio.

As a further step, the information and guidance systems (Fig. 4) such as the LISB system in Berlin, which is under trial with the participation of VW, not only contribute to optimum planning and implementation of the individual transportation task but also make possible an overall control of vehicle flows adapted to the particular traffic situation.

Fundamentally it must be made possible for each driver to know at any moment

- where he is,
- what route he must take to arrive at his destination,
- where he can park,
- where he can fill up, spend the night or find particular services
- how he can react to special traffic situations such as jams, weather-related hindrances etc., and
- at what speed he can quickly and safely negotiate individual route sections.

A promising approach in respect of the last points is the evening out of traffic flow by means of individual and flexible speed recommendations.

One possibility in this connection is to optimise the familiar "green wave" (synchronised traffic lights) (Fig. 5).
On the basis of the observed fact that the driver is not satisfied with one single speed recommendation, he is also shown his relative position within the "green wave". To be precise he is informed at what phase in the "green wave" he will approach the next traffic light at his present speed.

In the field trial of a system installed by Volkswagen in Wolfsburg, the so-called "Wolfsburg wave", in addition, within the display area for vehicle speed, on the one hand the recommended speed range is displayed via a series of LEDs and on the other the instrument shows the situation of the vehicle in relation to the green phase of the next traffic light. The data required for the on-board computer are transmitted by infrared transmission to the vehicle. Initial trials of this system have resulted in the improvements in emissions and consumption shown in the picture.

Further technical efforts in the field of driver information and thus of active safety in the vehicle are directed at measures for improving the keeping of distance between vehicles in traffic.

Many serious accidents, which appear in the official statistics as the result of "driving at excessive speed" are in fact due to the failure to keep an appropriate distance
from the vehicle front. In order to reduce the number of rear-end collisions in future, vehicles should be equipped with a distance measuring system.

For this a sensor head, for example of a pulsing infra-red laser, is located at the forward end of the vehicle, and electronics for data evaluation can be placed elsewhere in the vehicle (Fig. 6). Based on the speed of travel, it is calculated whether the measured distance from the vehicle ahead is great enough. Vehicle speed and distance travelled are measured remotely and without slip by a high-precision microwave doppler sensor. If certain limits are not attained a visual warning device is triggered.

This visual warning must be given to the driver in as direct and unmistakeable form as possible, without distracting his attention from the road precisely when it is most needed. A so-called head-up display (HUD) in the windscreen has an obvious application here (Fig. 7).

The HUD consists of a liquid crystal display which is freely-programmable. A projection lens acting as a magnifier projects the picture in such a way that it appears to the viewer to be at a comfortable distance such as the front bumper plane. The imaging of the information in the driver’s field of vision is effected by a semi-transparent mirror embedded in the windscreen, the so-called “combiner”. 
In addition to the advantage that in order to read the information there is no need to switch the line of vision from road to display, the adaptive effort of refocussing for distance is also eliminated. This is particularly important for older drivers.

Going beyond the optimisation of driver information, systems must be created which permit a better cooperation between all road users and in this way considerably reduce the probability of accidents.

The restricted perception of the driver and his limited overview of traffic conditions must be improved. This above all in critical driving situations.

Thus for the three accident types of side impact, rear-end collision and head-on collision, a frequency reduction can be shown in the case of an earlier driver reaction (Fig. 8). If the accident avoidance measures were to begin half a second earlier, these studies show that some 60% of rear-end collisions, 50% of side-on collisions and 30% of head-on collisions could be avoided. If the manoeuvre began one second earlier, over 90% of rear-end and side-on collisions and over 60% of head-on collisions could be avoided. It would thus be a significant contribution to active safety if it were possible to recognise potential accident situations half to one second earlier and to use this time for putting in train the correct manoeuvres for avoiding collisions.
And it simply cannot reflect the current state-of-the-art of vehicle and traffic technology when for example an accident in fog frequently leads to mass collisions of a hundred or more vehicles. Such a situation must be prevented by a communication network between the vehicles. For example, a vehicle involved in an accident must—in the way that an airbag is automatically triggered—emit a warning signal to inform the other vehicles.

ACTIVE VEHICLE SYSTEMS

Hitherto information improvements have been effected exclusively via the driver (thus indirectly) to the vehicle. This applies to traffic signs and radio bulletins alike. While they improve information (through aids to route selection and warning of weather and traffic conditions) they are nonetheless an additional burden for the driver at least at the moment of transmission. With the extension of traffic bulletins (RDS) and the above-mentioned permanent display for the green wave in the vehicle, at least the moment of information can be improved. But the addition of new and thus more comprehensive information can mean a considerable increased burden on the driver.

A reduction of the burden on the driver can only be achieved if the vehicle responds to certain information automatically. (One can imagine for example a control system such as would automatically observe traffic signs, from Halt...
signs to speed limits). This immediately however throws up the question of responsibility and driver acceptance (Fig. 9). The driver will scarcely appreciate having to share the driving with a control system. The vehicle would also then be a “servant of two masters”, with the need for a definition of responsibilities.

One possible solution is to place the entire responsibility on the control system. However this should in my view only be done where the machine is in a position to do the job qualitatively and quantitatively better than the driver. A positive example of this is the familiar anti-lock braking system.

Braking however is only one of the increasingly heavy demands made on the driver by today’s traffic, such as overtaking or negotiating bends for example, often under extreme conditions such as poor visibility, icy road surface, or constant exposure to stimuli, and to which he has to react correctly and fast. On top of this, drivers themselves have widely differing abilities and driving experience, and they have good and bad days. Consequently, in addition to brake systems, active aid systems must be conceived for the driver which combine the necessary features in a practical way.

MEASURES RELATING TO THE STRUCTURE OF TRAFFIC
In addition to an increase in vehicle intelligence and road infrastructure intelligence, in future new innovatory approaches to the problems of traffic in city centres will be necessary. If it is assumed that the desire to use an individual means of transport in this area too remains very strong, and on the other hand that pollutant and noise emissions on the spot have to be reduced to practically zero, and the road area required must also be reduced, then the only alternative is an electrically-driven compact vehicle.

The necessarily extreme conception of this vehicle for its specific application practically rules out its universal application. It makes more sense to rent out this means of transport for the city centre as required at parking lots on the periphery.

A transitional solution in the form of a Golf hybrid vehicle from VW Research (Fig. 10), on which it is possible to switch for example from normal diesel operation to electric drive, is already available for field trials.

Another logical step in this direction is represented by the Eco-Polo from VW which is currently undergoing fleet trials in Berlin.

In addition to the debate on future individual vehicles in city centres, the problem of parking vehicles in this area
must also be rethought. Additional parking space (Fig. 11) can in principle be made available through intelligent automatic-feed multi-storey vehicle parks, but will quickly reach its limits.

A more fundamental and thus more effective approach is offered by an overall supply-and-demand-oriented management of existing or new parking areas.

Without wishing to go into the ideological question of the superiority of the market economy over the planned economy or vice-versa, in my view practical experience shows that the market economy is clearly superior, as is currently being recognised in some Eastern countries.

But in Western countries with free market economies there are also planned detail solutions having the same results as in the East. Vehicle parking for example is administered in a manner having all the features of the planned economy:

1. The supply of driving and parking areas is planned.
2. The supply is generally inadequate.
3. The shortfall is not eliminated by the working of supply and demand, but is administered centrally.
4. The coveted object, in short supply, is distributed randomly: anyone lucky enough to find a parking space can keep it as long as he likes without paying what it costs to provide it.
With a market-economy solution, scarcity would lead temporarily to a price rise. This leads to an increasing, because profitable, supply. Obligations in respect of resources saving and environmental protection must apply here as anywhere else.

The attempts made hitherto at management of traffic space (road tolls, parking charges) have failed on account of the difficulty or imperfectness of control. It is often cheaper to pay an occasional parking fine than regular parking fees. The patient seekers after parking spaces correspond to the queues outside shops in a planned economy. In both cases the economy loses potential working time. Worse still: in both cases the citizen is resigned to the indolence of his economic system. In Munich for example it has been found that up to 70 % of city centre traffic is composed of drivers looking for a place to park.

The next illustration (Fig. 12) shows the essential ideas for a redesign of vehicle parking. The complete registering of traffic space utilisation, the automatic cost-covering payment for and better networking of available parking spaces are a precondition for the free-market development and management of traffic areas. In principle this schedules restriction of the use of available parking places in the city centre to residents and short-term parkers, with commuters being required to use multi-storey car parks
on the edge of town and special commuter buses to their inner-city place of work. For visitors wishing to spend several hours in the city centre, park and ride systems are set up at the biggest public transport stations (Fig. 13).

Although the park and ride idea is not new, its acceptance by users leaves room for improvement. I believe for example that this system is totally lacking in any kind of user-friendly infrastructure. There are excellent reasons therefore, in the framework of a new organisation of parking, to extend the logical enlargement of today's mass parking lots to include their transformation into generally attractive service park and ride centres. This involves, as I see it:

- ease of access
- ease of parking
- ease of changeover
- comfortable further progress by rail and bus
- an all-round service

CONCLUSION

In conclusion let me recap. We have to assume a further increase in passenger car population and traffic up to the year 2000. The development of individual traffic could be inhibited by a currently unforeseen change in the supply of oil. Even so, low-consumption automobiles and new energy
sources make dominance of individual traffic seem certain even under unfavourable framework conditions. The motor vehicle must, however, respond to the changed ideas of the year 2000 in regard to alternative traffic concepts and pro-environmentalism.

In the last analysis it is a matter of taking the decisive step away from traffic as the sum of many individual systems and towards an integrated overall concept in which actions can be implemented more foresightedly, more safely, and more humanly controllably.

This, according to CAPRA, first demands a different way of thinking, a changed perception of the world. One which is complex instead of linear, expressed in networks and curves rather than in straight lines and the graphs of statistics. Qualitative evaluation must take the place of quantitative measurement. Traffic too is more than the sum of its parts.
Verkehrsentwicklung in der BR Deutschland

Bus
Bahn
Flugzeug

Mrd. Personen-km


Quelle: VDA - Jahresbericht 85/86

VOLKSWAGEN Forschung.

Aussiehung relevanter Verkehrsgebungen durch Kenntnis des Fahrzeugstandortes (Navigationsanlage)

Verkehrsfunk über Satellit
Verkehrsfunk über UKW
Informationen von anderen Verkehrsteilnehmern
Informationsbaken

VOLKSWAGEN AG Forschung.

VTI RAPPORT 362A
Verwendung von RDS-Rundfunksignalen zur Standortbestimmung im Fahrzeug

Verfahren:
Standortbestimmung durch Laufzeitdifferenzmessung synchronisierter RDS-Signale

**Ziele:**
- Selektierung relevanter Verkehrsinformationen
- Stützung von Navigationsverfahren
- Ortung von Einsatzfahrzeugen zu Dispositionszwecken

**Technik**
- im Autoradio zusätzlicher Chip und Software zur Standortberechnung
- bei den UKW-Rundfunksendern einfache Netzwerksynchronisation der RDS-Signale

**Volkswagen Forschung**

### Fig. 3

#### Teilkonzepte

<table>
<thead>
<tr>
<th><strong>im Interesse der Kraftfahrer</strong></th>
<th><strong>im Interesse der Verkehrsbehörden und der Allgemeinheit</strong></th>
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<td>Verkehr steuern durch...</td>
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<td>Autarkle Navigation</td>
<td>Optimierung der LSA-Programme</td>
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<tr>
<td>Individuelle Zielführung</td>
<td>Geschwindigkeitsbeeinflussung</td>
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<td><strong>Informieren über</strong>...</td>
<td>Verkehr leiten durch...</td>
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<tr>
<td>Parkplätze, Park &amp; Ride-Plätze</td>
<td>Alternativroutenempfehlungen</td>
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<td>Tankstellen, Werkstätten</td>
<td>Trennung von Nah- u. Fernverkehr</td>
</tr>
<tr>
<td>Post, Telefonzellen</td>
<td>Trennung von PKW- u. LKW-Verkehr</td>
</tr>
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<td>Entzerrung von Verkehrsströmen</td>
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<td>Apotheken, Krankenhäuser</td>
<td>Parkleitsystem</td>
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<td>Stau, Unfall</td>
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**Fig. 4**

VTI RAPPORT 362A
Wolfsburger Welle, ein Beitrag zu Verkehrsleitsystemen

Verbesserungen durch die Wolfsburger Welle

- Kontinuierliche und aktuelle On-Board-Anzeige des individuellen Geschwindigkeitsspielraums, um fließend eine Folge von Ampeln bei Grün passieren zu können.
- Steuerung über einen Infrarotsender am Ampelmast, der die Schaltzeiten der Ampel und weitere verkehrstechnische Daten ins Fahrzeug überträgt.

VOLKSWAGEN Forschung

Prinzip der Abstandswarnung

- Fahrgeschwindigkeit \( v \)
- Abstand \( d \)
- Warnstufe 1
- Warnstufe 2

VOLKSWAGEN Forschung

Fig. 5

Fig. 6

VTI RAPPORT 362A
Moderne Anzeigetechnik mit Head-Up-Display
Funktionsweise

VOLKSWAGEN Forschung

Fig. 7

Abnahme der Kollisionshäufigkeit [%]

Unfallreduktion durch vorverlegte Fahrerreaktion

VTI RAPPORT 362A
Fig. 9

Diesel/Elektro-Hybridantrieb

Antriebsstruktur

Ziele:
- Einsparung von Motoren-Kraftstoffen
- Primärenergie für den elektrisch gefahrenen Anteil ist beliebig wählbar
- Geräuscharm und schadstofffreier Betrieb in Kurorten bzw. in zukünftig gespeisten Wohnzonen
- Erfüllung der Emissionsstandards wie Dieselmotor
- Für längere Fahrten (Urlaub) kann auf Elektromode o. Batterie verzichtet werden so daß wieder volle Zuladung möglich ist.

Meßergebnisse im ECE-Test
Platzsparendes automatisches Parken
Parksplatzprobleme intelligent gelöst

Parkorganisation
In Innenstadt Anwohner und Kurzparker
- Hohe Gebühren / mit Parkdauer ansteigend
- Lückenlose Erfassung
- Automatismus
- Sperrung ab 95% Belegung
- Parkleitsystem (Zahl der freien Plätze)
  Tagesparken (Angestellte)
- Parkhäuser außerhalb der City mit Zubringerbussen
  (morgens und abends 1 Stunde enger Pendelverkehr)
- Niedrige Gebühr
  Längere Einkäufe (2–3 Stunden)
- Park + Ride mit vorhandenem öffentlichen
  Verkehrssystem kombiniert
Service Park & Ride
Modernes Parken leicht gemacht

Fig. 13
Automotive Crash Safety Engineering -
Time for a New Approach?

Hugo Mellander
Volvo Car Corporation
Sweden
Hugo Mellander  
Volvo Car Corporation  

AUTOMOTIVE CRASH SAFETY ENGINEERING - TIME FOR A NEW APPROACH?

This paper will describe the history of automotive safety in terms of the major areas of progress in research, product development and legislative activities.

The current situation in the fields of safety engineering and governmental regulation will be assessed.

The present level of awareness in the epidemiology of traffic casualties, clinical diagnosis and treatment and biomechanics of impact trauma will be presented briefly and discussed.

The need for new data bases on human tolerance will be pin-pointed, as well as the incorporation of modern scientific tools in both analysis and engineering and the modernization and harmonization of safety regulations.

A model which represents an advanced approach to safety improvements in the product development process, and which is currently in use at Volvo Car Corporation, will be outlined.

The platform for all crash safety efforts is and always will be the comprehension of human tolerance to impact. The risk of possible stagnation in basic research due to lack of funding and institutional interest will be focused. Recommendations will be given for activities which could elevate the science of impact biomechanics and establish it as a recognized academic discipline.

The need for continuing public information to maintain and increase acceptance of safety equipment will also be discussed.
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Time for a New Approach?

Hugo Mellander
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The need for continuing public information to maintain and increase acceptance of safety equipment will also be discussed.
History

As a remedy for the increasing death tolls on the roads in the fifties, the automotive industry began to implement crash safety engineering into the development of new cars. At this time, the understanding of human tolerance to rapidly applied loads was low. It was therefore a necessity that research into the biomechanics of impact ran parallel to the efforts to introduce safety systems in cars.

Biomechanical knowledge was gained through the study of accidental or suicidal free falls, racing accidents and tests conducted with volunteers. It was found that the human body could take very high loadings for a short time if the forces acting on the body were well distributed.

The progress in biomechanical research was reported primarily at the annual Stapp Car Crash conference in USA. The conference is named after a research pioneer, Colonel John P Stapp who, as a volunteer, subjected himself to high g forces in deceleration tests on a rocket-powered sled.

In the automotive industry, the design of car frames and bodies matured into the development of crumble zones. The first attempts were made with restraining harnesses and the three-point belt with the sliding buckle was developed and installed as standard equipment in the front seats of cars in 1959.

During the sixties, the biomechanical research was intensive, and significant achievements were made. Tentative tolerance thresholds for severe injury caused by exposure to frontal collision, expressed in g:s for the head and the thorax and in pounds for the femurs for axial loadings, were established. The development of the first anthropomorphic test dummies made the use of this threshold data possible as injury criteria levels measured in test dummies in automotive crash testing.

Installation of the three-point belt in automobiles became widespread and, together with collapsible steering columns, padded dashboards, head restraints and laminated windscreens, cars became much safer.

During this decade, legislative activities started up in Western Europe, Canada, USA and Australia. The safety standards were either design rules or performance requirements. These standards were primarily devoted to the approval of components. Neither the safety systems nor the whole car were subjected to any approval testing, with the exception of a proposed regulation in USA for approval of passive restraints through a barrier impact test at 30 mph with instrumented dummies in the car. This regulation became known as the FMVSS 208. It was part of a whole series of safety standards, the FMVSS (Federal Motor Vehicle Safety Standards) series, introduced in 1968.

During the first half of the seventies, biomechanical research grew in both quantity and quality. Experimental cars were developed in the ESV (Experimental Safety Vehicle) program. In this research program, initiated by the NHTSA (National Highway Traffic Safety Administration) in USA, contracts were given to different institutes to develop safety vehicles. The results were reported at an annual (and in recent years a biannual) conference, which soon became a very important forum for exchange of ideas and information.

In Europe, the first IRCOBI (International Research Council on the Biomechanics of Impact) conference was held, and this conference became instrumental in reporting and coordinating European research.
Crash test facilities were built in many countries, and the scientific community working with injury prevention was substantially enlarged.

During this period, the safety systems in cars were refined. For the first time, test fleets of airbag-equipped cars reached the market, but only in USA.

The engineers and management of the auto industry began to learn about the biomechanical terminology (1), such as severity indices, and later on about HIC (Head Injury Criterion) values (19) and chest g:s - examples of injury criteria used in a test dummy in crash testing.

It was during this time that the proposed performance standard for passive restraints in USA, mentioned above, started to influence the evolution of safety research, even if the standard was not enacted until many years later (2).

During the latter part of the seventies, the EEVC organization (European Experimental Vehicle Committee) initiated a biomechanical research programme, sponsored by EEC, in order to fill the existing gaps in biomechanical knowledge. The most interesting research was perhaps the study of side impact. These activities were paralleled in USA. Human tolerance to lateral loadings, side impact dummies, and countermeasures built into cars were tested.

At a large conference in Brussels in 1983, researchers and regulators from Europe and USA met to report and discuss the results from these programmes. The need for harmonization and structuring of safety regulation was strongly emphasized, but in spite of this, very little harmonization, if any, has occurred. The activities within regulation were consequently very limited during this period.

In the eighties, the scientific tools were vastly improved. Better planning of experiments, new instruments, faster and cheaper computers in conjunction with mathematical models, improved the quality of the safety research, although the amount of basic biomechanical research was decreased.

The work to design a side impact dummy continued, and it is interesting to note that Europe, through the EEC-sponsored and coordinated programmes mentioned above, made quite a significant contribution in this field. Anthropomorphic crash test dummies have primarily been designed and manufactured in USA. A result of the EEC programme is the so-called Eurosid side impact dummy, which may become an alternative in pending American side impact regulation.

The most noticeable safety features introduced during this period were the driver airbag, preloading belts, antishubmarining devices in the seats and accessory three-point belts for the centre position in the rear seat.

Today

Now, in 1990, we are at a point where cars have been considerably improved in terms of safety, and there is a substantial network of safety standards to ensure the maintenance of this safety level. The question is whether they do this effectively, or whether the industry is burdened with a complex and unsystematic network of safety standards. Is it possible that, in the interests of the car buying public, a more systematic approach and a harmonization of safety standards would yield better cars, to a lower price?
As an example - the characteristics of the seat belts are now an important parameter in the mass and damped spring system that governs the forces acting on an occupant in a crash. Yet, for a seat belt to be approved in Europe, it has to pass a very crude dynamic test with a standardized crash pulse, a steel seat and a simplified dummy. Constant efforts to replace this test by a so-called global test similar to the American FMVSS 208 have been going on for over ten years.

**Epidemiology**

As a platform for the continuing discussion in this paper, current statistics of traffic casualties will be given.

In Sweden, 813 people died and 5869 were severely injured during 1988. Approximately 65% of these were car occupants. The corresponding figures for EEC are 50,000 and 1.6 million. Car occupants represent approximately 55% of the fatalities and close to 60% of the casualties. In the world as a whole, at least half a million die and about fifteen million are injured in traffic accidents every year (3). Depending on the country, the percentage of car occupants can vary from 30% in developing countries to 70% in heavily industrialized countries.

A forecast has suggested that by the year 2000, the fatalities could reach one million (3).

Traffic casualties can never be totally reduced by countermeasures to the vehicles but, nevertheless, every effort has to be made to try to reduce human suffering and the cost to society.

**Clinical diagnosis and treatment**

Rescue teams with short access time, efficient trauma centres, improved clinical diagnosis and treatment are all factors which can contribute to saving victims that would otherwise be lost (4). In western Germany, a very efficient network of trauma centres exists, and similar systems can be found in Australia and in some states of USA.

The diagnosis of closed head injuries has been dramatically improved by the computerized tomography and magnetic resonance techniques. However, we still lack the understanding of the injury mechanism behind these injuries.

Spinal injuries are still very difficult to treat and heal. They often result in functional losses. Leg injuries, especially in the joints, often result in lasting handicaps.

**Where does biomechanical research stand today, and what is missing?**

- Through the use of human cadaver testing, the study of real accidents and through tests with volunteers, biomechanical research has reached a level where the impact response and injury levels for the thorax are quite well defined for both frontal and lateral loadings. This is also the case for the axial loading of the femur.

- The mechanism of skull fractures and contusions to the brain is partly understood, but considerable gaps still exist in the understanding of the tolerance of the brain to both linear and angular acceleration (5,6).
- There is some basic information about facial bone fractures levels, and this area has been given increased attention recently (7).

- The response and injury levels of the cervical spine are not assessed in any detail.

- The fracture mechanism for the thoracolumbar spine is defined for vertical accelerations, but little is known about other directions of forces.

- The visceral organs in the thorax and abdomen need to be better defined in terms of response and injury tolerance, although some progress has been made with the introduction of the viscous criteria (8,9).

- The response and damage levels of the legs and their joints are being studied at the moment, especially in Europe. This work is, however, concentrated to pedestrian injuries. More research is required on all the longbones and their joints, with the exception of the femur.

With the introduction of the Hybrid 3 dummy, the anthropomorphic test dummies have been considerably improved, but the dummy still lacks biofidelity and instrumentation. A compliant force measuring face and improved instrumentation for the measurement of the angular acceleration of the head are two ongoing projects with top priority.

It is now understood that human tolerance varies, depending on age and individual factors. The correlation between these factors and injury levels is poorly known (1,17). This is an area which requires a lot more attention in order to avoid having safety systems tuned only to the average human being. The consequences could be, for instance, that padding materials are developed which would not be deformed by the weaker part of the population - thereby excluding them from protection.

Biomechanical research was, for a long time, trapped in the regulatory dilemma of assessing one specific injury criteria level as a threshold level with non-injurious values on one side of this threshold and injurious values on the other.

As an example, the head injury criterion (HIC) values of 1000 can be mentioned. For everyone but the most initiated, it was understood that if HIC was 999 there was no injury and if HIC was 1001 there was a severe injury. This was a misinterpretation of the original data from the sixties. Recent advances in experimental statistics and the interpretation of censored data (10,11) have given us probability functions which allow for much more sophisticated inductions. A specific value of an injury criterion yields the information that, with a certain confidence level, a specified section of the population would have been protected from injury if exposed to the same violence.

This sort of reasoning must be incorporated in all injury reduction calculations made by society and industry for better prediction of the effects of introduced countermeasures.
A model for systematic safety engineering

At Volvo Car Corporation we have, for a long time, used a systematic approach in our engineering process. (12) The model is based on our accident investigation research and reproduction of the road environment in experiments in our laboratories. Through design and test loops the cars are developed and finally reach production and the customer. The continuing follow-up of real accidents ensures that any necessary design changes and improvements are found and fed into the system. See Fig. 1.

Recent research has made it possible to develop this model even further. A statistical model which couples laboratory experiments to the outcome in real crashes makes it possible to assess engineering targets in terms of the injury reducing effect for a specific design (13).

It is a known fact that the majority of automobile crashes occurs at a relatively low crash severity. A hypothesis has been put forward that crash testing at high speeds like 35 mph might lead to suboptimization of safety systems (14). Using our model, it will be possible to experimentally check the crashworthiness of a new car in order to avoid suboptimization and to predict the injury reducing effects with a high degree of confidence.

It is not the purpose of this paper to describe this model in detail. Some basic information will, however, be given.

Fig. 1. Volvo engineering methodology

Recent research has made it possible to develop this model even further. A statistical model which couples laboratory experiments to the outcome in real crashes makes it possible to assess engineering targets in terms of the injury reducing effect for a specific design (13).

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It is not the purpose of this paper to describe this model in detail. Some basic information will, however, be given.
Accident statistics make it possible to describe injury as a function of a crash severity parameter for a well defined impact configuration. For a specific car model it is possible to draw a curve as depicted in figure 2.

**Fig. 2. Injury risk at each Crash Severity (CS) level**

By reconstructing the collisions at different speeds with test dummies and measuring the injury criteria in these dummies, it is then possible to correlate dummy response with injury risk as depicted in figure 3 for a specific impact condition, e.g. well distributed frontal impact.

**Fig. 3. Converting injury risk vs. crash severity \( P(I|x) \) into injury risk vs dummy response \( P(I|d) \)**

Once this correlation is found, and with a knowledge of the crash severity distribution, the data can be used to set up engineering targets expressed in functional requirements such as maximum allowed chest acceleration at different crash speeds, in order to achieve a certain injury reduction. The model can also be used to calculate the injury reducing effect of a design if the dummy responses are known for a sufficient number of test speeds.

Further improvements have been made to the development process by the introduction of crash tests in an increased number of impact directions and engagements such as side impact (15) and offset collisions.
We have also included functional requirements for the dummies in the rear seat. This has led to the engineering of an integrated three point belt and head restraint in the centre position of the rear seat of the sedan models in the new 940 / 960 series. For children who have outgrown the child seat, the same models have an integrated booster cushion in the armrest of the rear seat as an option.

The new approach will give improved safety for all occupants in the car.

On the whole, this new development model will contribute to the technical advancement of our cars.

Fig. 4. The rear seat with booster cushion in armrest and 3-point belt in centre position
Recommendations for the future

The interest is now going to be focussed on the prevention of severe and disabling injuries. It is of vital importance that the scientific institutes are given the funds and human resources needed for making the basic research in these areas. The lack of funding to injury control compared to that spent on disease control is well documented (16).

It is also notable that there are less than ten universities in the world offering academic training and a doctor's degree in biomechanics.

Our recommendation is that impact biomechanics should become an internationally recognized academic discipline and that government interest and sponsoring are increased.

One way of initiating such an activity could be through the establishment of an international traffic safety foundation, as suggested here two years ago (3).

The auto industry must continue to refine its safety engineering by using modern tools such as those described in this paper.

The individual perception of risk during exposure to traffic has been elaborated upon in many articles (18). It must be emphasized that a continuing flow of information about the available safety systems in today's cars is of utmost importance.

All new drivers and car occupants must be given the proper training and means of understanding how the safety systems work and how they should be used for optimal efficiency.

It is equally important that the education given at school early in life should give an elementary understanding of the physics of colliding objects and man's tolerance to trauma, for us to be able to comprehend the consequences of a crash.

At Volvo, we are presently developing and evaluating an information package using video, radio tape and PC media. If successful, this approach could be used to inform future customers about the safety systems in our cars.

Information and education are the only means of increasing the public awareness of the consequences of high risk driving and the effect of not using the available safety systems.
Conclusions

Injury prevention by improving the crashworthiness of cars is a truly multidisciplinary task. It involves experts in medicine, biomechanics, epidemiology, statistics, computer analysis, testing and engineering.

All safety engineering efforts must, however, be based on a thorough knowledge of the human tolerance to impact. Distinct progress has been made in crash safety, using tentative biomechanical injury criteria established in the sixties. To make further progress in injury reduction, the engineers must be supported by new biomechanical basic research findings leading to improvement of the already existing criteria, but also to new criteria - primarily for the head, cervical and thoracolumbar spine, extremities and visceral organs.

It is recommended that the science of impact biomechanics should be recognized as an academic discipline.

The implementation of modern statistical tools, such as described in this paper, into the engineering process of modern cars is recommended.

There is a complex network of safety standards, which differs between countries, continents and political and economic constellations. These standards must therefore be harmonized and rationalized to facilitate product development, with the ultimate goal of giving the car buying public a better product, at a lower price.

Education and information about safety and the use of safety equipment must be continuous. The use of modern media techniques to spread this information invokes exciting opportunities.
References


The Daimler-Benz Driving Simulator
Research for Road Safety and Traffic Environment

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The Daimler-Benz Driving Simulator

Research for Road Safety and Traffic Environment

Authors: Volkhard Schill, Wilfried Käding, Daimler-Benz

The Daimler-Benz driving simulator is a tool for car development and driver behavior research. It has been used also for road design studies concerning traffic regulations and safety as well as for reconstruction of special accidents.

Some experiments which deal with these applications will be discussed in detail:

- Different speed reducing measures led to a significant reduction of speed in a Dutch village. Several combinations of this measures are examined and compared with the results in real world.

- The reconstruction of an accidental scenery with an gasoline carrier with respect to road, vehicle and environmental data is used to find out the reasons for the real accident.

- German traffic laws concerning the range of sight at the entrance to tunnels are tested with different tunnel widths.

For further research a urban environment is presented which can be used for different investigations about urban traffic planning.
The Daimler-Benz Driving Simulator
Research for Road Safety and Traffic Environment

Volkhard Schill
Wilfried Käding
Daimler-Benz AG

1. Abstract

The Daimler-Benz driving simulator is a tool for car development and driver behavior research. It has also been used for road design studies concerning traffic regulations and safety as well as for reconstruction of special accidents.

Some experiments which deal with these applications will be discussed in detail:

- Different speed reducing measures led to a significant reduction of speed in a dutch village. Several combinations of this measures are examined and compared with the results in real world.

- The reconstruction of an accident scenery with a tanker truck with respect to road, vehicle and environmental data is used to find out the reasons for the real accident.

- Driving at the entrance to tunnels is examined with different tunnel widths.

For further research an urban environment is presented which can be used for different investigations about urban traffic planning.

2. Driving Simulator Design Overview

Figure 1 shows the overall design of the driving simulator. The test driver sits in a compartment (3 in figure 1) which strongly resembles a complete car or truck cabin. The computer model of the respective vehicle dynamics is driven by the driver's control action. The computed resulting state of the car and the world surrounding it is presented to the driver by means of several satellite systems. One of these systems is the image generator which computes the image of the landscape surrounding the driver. The computed landscape image is then projected (2) onto the simulator dome (1). Another satellite system is used for motion simulation (5) which, by moving the whole dome, creates the acceleration cues for the driver. The third system creates the car specific noise which is presented to the driver via several loudspeakers. Operation of the simulator is supervised from a control station (10), from which the test engineer is able to control all simulator subsystems.
The Daimler-Benz driving simulator has been used as a research tool for vehicle development in many experiments (HAHN, KÄDING 1988). Beyond this several tests with more driver orientated investigations took place. The field of traffic environment has been examined in newer experiments as well. The latter will be described in this paper.

3. The effect of different speed reducing measures in simulator and reality

In 1977 a research program was started in the Netherlands to improve road safety in residential areas. Governmental funds were provided for carrying out field trials to investigate the effectiveness of different measures in modifying the behavior of road users.

During this program the entrance area of the village Weiteveen in the Netherlands has been modified to reduce the speed of approaching traffic. The following measures have been introduced to reach this aim:

- a traffic island was built on the road beginning approx. 130 m before the village entrance,

- a portal gate of yellow poles was constructed at the village entrance to narrow the visual profile and to highlight the entrance,

- after the entrance a different colored road surface was used and road markings at side and median were removed.
The average speed at the entrance area has been measured before and after the introduction of these measures. It changed from 72 km/h before to 65 km/h after the installation of all measures. People driving with higher speed outside (V > V85) reduced their speed more than the ‘average’ drivers.

The installation of these measures together with the analysis cost more than 1.5 Million Guilders. It is not possible to figure out whether the installation of only one or two of the measures would have led to similar results for less costs or whether the speed reducing effect would have been significantly worse. This question can be answered with a simulator experiment, where the achievable speed reducing effect with all possible combinations of the three measures can be analyzed. Besides this the validity of simulator experiments can be verified by comparing the existing data from real world with the data obtained in the study.

3.1 Design of the simulator study

For the simulator study a village was built in the image generating computer system. The course of the road and the buildings along the street were implemented according to maps of Weiteveen. The three measures (traffic island, gate construction, different road colors) were generated in a way that their appearance could be switched on and off independently. Figure 2 shows the village in the simulator without any measure, figure 3 with all three measures.

The road in the village was about 725 m long and 6.6 m wide. It was integrated in a 4.1 km stretch outside the village. This segment was repeated 12 times during one run, each time with different configurations at the village entrance.

The influence of learning effects and fatigue could be observed by varying the order of the different entrance situations. The speed difference should be the same in the combination before/after introduction of all three measures and in the after/before combination. By achieving similar speed differences in both sequences the validity of this simulator experiment would be proved.

The field experiment had shown that fast drivers reduce their speed more than slower drivers. To get the chance to reproduce this in the simulator experiment two different instructions were given to the subjects:

I: drive relaxed and don’t hurry,

II: drive as fast as conditions allow, you are in a hurry.
The results from these two different driver groups compared with the real world results would provide further evidence supporting the validity of this study.

The study was accomplished with 24 male subjects, 20 - 35 years old. Each one passed the before/after and after/before combination three times. The situations with one or two measures were passed six times. One run took one hour at most. With a sampling frequency of 5 Hz the following data were collected:

- Position of the vehicle on the road,
- Speed of the vehicle,
- Accelerator pedal position,
- Braking force.

3.2 Results

The mean speed profiles for all subjects at the village entrance dependent on the different numbers of measures can be seen in figure 4. The speed without any measures (upper curve) is significantly higher than the speed with all three measures (lower curve). Each measure alone has a significant effect on the driver's speed. The addition of an additional measure has a smaller effect compared with the first respectively second. There is only a small difference in speed between the different two by two combinations of measures, as well as for the individual measures.

![Fig. 4 Mean speed profile for all subjects with different number of measures](image1)

![Fig. 5 Mean speed profile for all subjects in real world and in simulator](image2)

It is obvious that there is a direct interaction between the speed and the quantity of speed reducing measures. The speed before/after the introduction of the three measures in reality and in the simulator study - separate for the two instructions - can be seen in figure 5. The acceptance of the instructions shows the difference in speed between the two groups. The higher approach speed in simulator is probably due to the fact that the speed limit on rural roads in Germany is 100 km/h compared with 80 km/h in the Netherlands. Besides this the high powered car (Mercedes-Benz 190E), the less detailed road environment and the low traffic density in the visual scene may be responsible, too.
The speed reduction at the village entrance is nevertheless equal or even higher than in reality. This may be caused by a more law conforming behavior under observation. The greater deceleration of the faster drivers is similar to the results in reality.

The analysis of the difference between the order of the situations before/after the introduction of all three measures indicates a distinction only at the first two village entrances. The following repetitions led to identical results for both orders.

This can be taken as an evidence for the independence of the experiment from the order of the situations and consequently for the validity of the study. The village entrance with traffic island, gate construction and different road color shows a significant speed reduction as it could be seen in reality. (A more detailed analysis of this study can be found in ALINK, OTTEN, 1990 or RIEMERSMA et al., 1988).

4. Reconstruction of a tanker accident

In the analysis of accidents involving commercial vehicles with dangerous cargoes several points become known:

- Vehicles carrying dangerous goods are involved in accidents more often outside built-up areas and on motorways, while ordinary commercial vehicles tend to have more accidents within built-up areas.

- Frequent types of accident for vehicles carrying dangerous goods are 'frontal collision' on rural roads and 'going off the road' on major roads.

- Compared with ordinary commercial vehicles, fast driving is more often the reason for an accident with dangerous-goods vehicles.

Because of the small number of accidents involving tanker trucks, the statistical data is incomplete. The use of the simulator for the reconstruction of a tanker accident provides a new approach to research, making it possible to investigate the system of driver/vehicle/environment in critical situations.

In the test carried out with the simulator, particular importance was attached to the question of how much the movement of the cargo (wave effect) can be a contributory cause of an accident, either directly, or, via the driver's motivational level, indirectly.

4.1 The real accident

For the simulator study a characteristic accident was selected which consists of a frontal collision between a tanker and a car on a rural road. This accident took place on a dry road at good visibility. A car drove with a speed of 100 - 110 km/h in a right bend. The tanker drove with 65 km/h in the opposite direction. The upper speed limit for both was 50 km/h. At the end of the bend the car got with his left front wheel approx. 30 cm on the oncoming lane. This was followed by a collision from the left side of the car with the left truck front (figure 6). Although the car was notified very early, the tanker driver took no evasive action. He stayed on his lane with an orientation more to the median than to the shoulder and broke. His collision speed was approx. 45 km/h. The
driver of the car was killed, his front-seat passenger was wounded. Nothing happened to the tanker driver.

4.2 The simulator study

For the study the road at the accident area was modelled in the visual system of the simulator with a length of 5.5 km. The width of the road was 6.4 m with a 0.6 m hard shoulder on both sides. This road segment was accomplished by existing parts of two lane rural road to a total length of approx. 16 km for the whole stretch. The traffic signs and the surrounding landscape were reconstructed from pictures and maps.

During the test drive there was opposing traffic from cars, trucks and buses. The opposing car at the accident situation drove at the end of the bench 30 cm on his oncoming lane (figure 7). Its speed was linked together with the test drivers speed in the simulated tanker \( \frac{V_{\text{car}}}{V_{\text{tanker}}} = \text{constant} \), so the accident situation always took place at the same place as in reality.

![Fig. 6 The accident situation in reality](image1)
![Fig. 7 The accident situation in the simulator](image2)

The mathematical model of the truck was enlarged with a model for slushing liquid to a Mercedes-Benz 1628 tanker truck with two half-full tanker chambers.

All 20 test persons were professional drivers with a mean of 20 years driving experience who regularly carried dangerous goods. To ensure that the test persons were totally unprepared when the situation occurred, they were told that the experiment concerned measuring driver-stress while driving on rural roads. After approx. 15 minutes of driving, the accident situation occurred. 17 parameters of the tanker were measured and recorded with a sampling frequency of 50 Hz during the accident situation, including:

- Steering wheel angle,
- Brake operation,
- Accelerator pedal position,
- Vehicle position,
- Distance from collision vehicle,
- Driving speed.
The drivers heart rate frequency was recorded with an earclip. The test drive was followed by a series of questions, in which the drivers were asked to describe how they experienced the accident situation and how they reacted during it.

4.3 Results

During the study two drivers had a frontal collision with the car as in the real-life accident. Neither of them took evasive action, but they broke. 15 drivers took evasive action to avoid the accident. By doing so they left the road and were driving on the hard shoulder. One driver drove so far to the right, on the hard shoulder, even before the bend that preceded the accident spot, that there was no danger of a collision even without taking further evasive action. Only one driver succeeded in both avoiding the frontal collision and staying on the road. One test drive could not be completed due to technical problems.

The test persons in general drove more slowly in the driving simulator than in the real accident situation. The speed limit signs in the area of the accident spot were obeyed by all the drivers.

The collision speed of the two accidental drivers was 16 km/h and 22.5 km/h respectively.

16 of the 19 drivers preferred leaving the road to avoid a collision. Their steering wheel angle had a maximum at 110 degrees, the corresponding speed was up to 305 degrees/sec. The driver with the optimal result - no collision and staying on the road - took soft, but very early steering action. Besides this his speed at the critical moment was only 17 km/h, compared with 45 km/h at the real accident.

In the question session 15 drivers said they were prepared to accept the risks involved in leaving the road.

Four drivers wanted to avoid evasive action with a tanker if this could mean going off the road. Two of them acted corresponding to their statements and accepted the fatal consequences for the car driver, the two other drivers took evasive action despite their opposite statements.

In the random sample of drivers 20% exhibited mental barriers to taking action which stemmed from the motivational level. Probably the causes lie in the fact that the effect of the sloshing liquid on handling makes the drivers feel less confident. Also, the drivers feel that the risk of fire or explosion as the final result of evasive action is very high.

5. Driving at tunnel entrance areas

The design of the transition area from road to tunnels has an influence for the driving behavior. There is no general analysis of this behavior yet, due to the fact that it is too expensive or - for reaction experiments - too dangerous to get the necessary data. This data is useful for the planning of tunnel entrances with respect to cost as well as to safety aspects.
Existing investigations show that 60% of all accidents in tunnels happen at the entrance area. The most frequent reason for accidents is collision with slower cars.

The driving behavior and especially the reaction at obstacles was to be examined in a simulator study. The question, whether the subjects get a realistic impression at the tunnel situations and whether technical aids can make the driving more safely, was to be answered too.

5.1 Design of the study

The test stretch was an approx. 48 km long rural road. It was constructed with six different road segments. The width of the road varied from 6.6 to 8.0 m. Two different tunnels, a smaller with 7.0 m road width (10 T) and a bigger with 8.0 m (12 T) were used. Four tunnels had to be passed by the subjects in either the sequence 10 T, 12 T, 12 T, 10 T or 12 T, 10 T, 10 T, 12 T.

The tunnel consisted of a 55 m ramp and a 195 m entrance area on both sides and 1500 m darker tunnel area between (figure 8). In the third tunnel there was an obstacle lying on the road, a black cube with 0.5 m edge length. It was located in the entrance area, 46 m behind the portal and 1.0 m right of the median. It could be seen from a distance of 160 m (figure 9).

Fig. 8 Tunnel entrance area          Fig. 9 Obstacle in the tunnel

Several stones as obstacles on the road outside the tunnel were located in a right bench between the third and fourth tunnel. They could be seen at a distance of 96 m.

There was opposing traffic all the time except at the tunnel, the tunnel entrances and at the obstacles. There was no traffic in the test drivers direction.

Nine parameters were collected with a sampling frequency of 5 Hz, including:

- Position of the vehicle,
- Speed of the vehicle,
- Accelerator pedal position,
- Braking force,
- Distance to median.

The simulated car was a Mercedes-Benz 190E with automatic transmission.
21 male and seven female subjects were chosen. All of them had some years driving experience but none had joined a simulator study before. After the drive the subjects had to answer some questions about their impression of the realism of the simulated landscape.

5.2 Results

The analysis of the subjects data showed that young drivers with only little driving experience tended to drive faster than the average. Female or older subjects were driving slower and the more driving experience people had, the faster they drove.

The driving behavior of all subjects showed some significant characteristics which were independent from their speed level. All drivers reduced their speed to a minimum at a distance of 150 m to the tunnel entrance. After this point they accelerated continuously. The average speed inside the tunnel was approx. 20 km/h higher than the speed at the entrance area. The same behavior could be observed in real world investigations.

The speed was reduced by 15-20 km/h when the end of the tunnel came into sight. There was no difference in speed between the smaller and the wider tunnel.

There was no uniform reaction to the obstacle in the tunnel. Three drivers drove over the obstacle because they didn't recognize it as dangerous. One third of the subjects reacted within an area of 120 - 140 m before the obstacle by taking back the accelerator pedal. The brake was used approx. 62 m after this reduction of speed.

Seven drivers stopped in front of the obstacle, one passed without braking and one third reduced its speed by up to 50 km/h. The rest passed with only a small speed reduction.

All subjects, except one, passed the obstacle in the wider tunnel at the right side, that means on their own lane. In the smaller tunnel half of the drivers passed right, half left.

The reaction to the obstacle on the rural road by using the brake started approx. 66 m in front of the obstacle. Seven drivers broke very hard and passed the obstacle slowly, one could not avoid an accident because he was too fast. The rest passed after soft braking action.

The analysis of the questions yield to a realistic impression at the tunnel entrance area. The recognition of the obstacles was assessed as good, too.

The behavior of each subject was similar at both obstacles. Drivers who broke very hard in front of the obstacle in the tunnel did the same on the road outside. The more uniform reaction to the obstacle outside the tunnel compared to the obstacle inside is a good indicator for the special situation at tunnel entrances, which is characterized by a high uncertainty.

This could probably be changed with the help of optical and/or electronic aids at the tunnel entrance area, which indicate obstacles and slower traffic. The design of these aids requires further investigations. (A more detailed analysis of this study can be found in PASDERSKI, SCHILL, 1990).
6. Presentation of an urban environment

An urban environment has been introduced in the simulator landscape. It is constructed with several multi-level buildings, roads, sidewalks and different types of crossroads. Smaller houses, a supermarket, telephone-boxes, bus stops, benches and trees may be integrated, too. The crossroads can be equipped with traffic lights, traffic signs and pedestrian crossings. Several traffic signs may be placed in the city, which can be integrated in the simulator landscape with different types of rural roads, highways, a village, etc. Figures 10 and 11 show two scenes in this city.

![Crossroads in the city with pedestrian](image1.png)

In this environment several investigations may take place. The differences in speed between traffic regulation with standard right of way, traffic lights or traffic signs could be observed as well as the reactions to dangerous situations, caused by other cars, a bicyclist, a dog or a pedestrian.

Another application is the development of route guidance systems which may be tested in advance.

Besides this several more investigations may take place in this urban environment.

7. Conclusion

The validity of the Daimler-Benz driving simulator for road safety and traffic environment research has been proved with all the described studies.

The effect of changes in road environment may be tested in advance, without any field trials and with high flexibility. The understanding of driving behavior can be increased and the reconstruction of real accidents may be used to avoid further accidents. In these experiments the simulated traffic and the environment force the drivers to react as in reality even in dangerous situations, although there is no danger while driving in the simulator.

The environment in the simulator is adaptable and becomes enlarged for the analysis of future questions.
References


The VTI Driving Simulator
Trends and experiences

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ABSTRACT

Since its launch in 1984 the VTI Driving Simulator has been used in a large number of studies. During that period a continuous development work to refine and improve the different subsystems has also been carried out. This report will give an overview of these studies in different areas and the improvements and modifications that have been introduced since the start.

The report will also describe a new driving simulator that is currently under construction at VTI for a Swedish insurance company TRYGG HANSA. This simulator is designed to be able to house both heavy truck and passenger car cabins and is intended both for research and the training of drivers. The moving base will have the same degrees of freedom and performance similar to the VTI system but the general layout is different to get a more cost effective solution. The basic philosophy behind the design will be described and compared to some recent efforts in the simulator field.
THE VTI DRIVING SIMULATOR
Trends and experiences

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1. INTRODUCTION - CHAPTER 1

Since its launch in 1984 the VTI Driving Simulator has been used in a large number of studies. During that period a continuous development work to refine and improve the different subsystems has also been carried out. This report will give an overview of these studies in different areas and the basic philosophy behind the design of a new driving simulator which will be completed in the autumn 1991 and situated in Stockholm near Arlanda airport. This new simulator will be one of several other equipments housed in a large exhibition and research centre, PROTECTUM, that is currently built up by the Swedish insurance company TRYGG HANSA.

Both these simulators are exponents of low budget systems in contrast to the Daimler Benz system (1) and that outlined in (2) for a National Advanced Driving Simulator in the USA. In this context the meaning of "low" is relative. The original VTI simulator cost roughly 25,000,000 SEK to develop translated to the current prices, which for VTI was a major investment. In the development work we have tried wherever possible to use commercially available equipment and simple solutions. This shows for example in the visual system where we use standard TV-projectors made by BARCO and a cylindrical screen just painted white. No attempt has been made to use highly reflective aluminium paint, which is costly, very easily damaged and must be repainted fairly often.

2. THE VTI DRIVING SIMULATOR - CHAPTER 2

Several modifications and improvements have incorporated in the VTI simulator during the years. For a more complete description readers are referred to earlier reports e.g. (7). Here we concentrate on more recent changes and the reasons why they have been introduced.

2.1 Visual system

There are several reasons why we have chosen to develop the visual system ourselves. Price will exclude the use of advanced graphics systems that are commercially available but there are also technical reasons. The transport delays in these systems are normally quite high, typically 80 ms or more, and this will limit the possible uses for a driving simulator. This is especially critical for severe handling manoeuvres. It
may still be possible to distinguish between different handling qualities but the longer transport delay the more obscured are the results from the researcher’s point of view.

The visual system has undergone several development stages since the simulator was put in use. Still the main characteristics are the same. The image is generated in real time in a specially designed image processor controlled by the main computer. The image is transformed to a standard video signal in European PAL-format with separated RGB components and standard resolution of 625 lines and 832 pixels.

The system is extremely fast with a transport delay of 20 ms resulting in a total transport delay of 40 ms including the integration time step of the vehicle model (20 ms) and the time for scanning the projector screen. The price for this speed is of course some lack of versatility and slight deficiencies in picture quality regarding resolution and flicker. A realistic road surface with easily changed texture can be produced. This includes lines, tracks, pot-holes, different surfaces, borders of snow and so on making the appearance of the road itself realistic. The horizontal and vertical road curvature as well as the road width can easily be varied even on line and it is very easy to reconstruct a given road when the curvature data are known. The sight conditions are also very easy to change with a range from a clear day to fog or darkness. The road and its surface may thus be simulated to a high degree of realism but the outside landscape is very sparse in details consisting only of chequered fields in different colours and texture.

Substantial effort has been laid down to introduce objects (static and movable) and the first results of this will be used in experiments this year. This will broaden the possible uses of the VTI simulator, since earlier it has not been possible to make any studies of interacting traffic and obstacles. The development work is however extremely difficult and time consuming since it involves both hard- and software in a non-standard application.

Most drivers complain about their eyes feeling strained after a session in the simulator. This is not surprising since the visual generation itself creates much flicker in the picture, standard interlaced PAL system is used and the driver sits very close to the screen (2.5 m) to get a horizontal view angle of 40 degrees/projector. Problems of flicker can be decreased by improvements in the visual generator itself, but this will normally cost one frame increasing the transport delay in the visual system with another 20 ms. For vehicle handling experiments such extra delays should be avoided but for less taxing applications like alertness studies a reduction in flicker could be more beneficial than a low transport delay. In fact, visual systems for driving simulators should offer both possibilities, namely an
extremely fast system with little details for handling tests and a somewhat slower system, where the picture quality and versatility are very high, for other tests where the handling quality of the car is not important. It should however be observed that even the envisaged slow high quality picture system must be much faster than what is normally accepted in flight simulators (typically < 150 ms).

2.3 Interchangeable cabins

To meet the increasing demands to use the simulator, not least from different DRIVE and PROMETHEUS projects, a system has been installed which makes it possible to change cabins. There are two cabins available, one VOLVO 760 with automatic gearshift and one SAAB 9000 with manual gearshift. The different cabins are bolted to the vibration platform consisting of an upper frame connected to the moving base with hydraulic actuators and rods. The cabins are handled by a big crane specially built for the purpose.

Mounting new equipment in the simulator cabin is thus much easier to do now since it can be done with the cabin on the laboratory floor rather than in the cramped surroundings one meets inside the simulator.

2.4 General observations about the moving base

Most driving simulators can be experienced as quite bad by choosing an unsuitable combination of manoeuvres and road curves. The main problem is the generation of steady state lateral acceleration when driving in a curve. This must be done by giving the cabin a specified roll angle with the following consequences:

- The attainable steady state lateral acceleration in the simulator is much less than 1 g since a component of the gravitational acceleration is used
- Very large lateral motion and high speeds are necessary if the lateral acceleration and the roll motion are combined to give the desired acceleration signal under the restriction that the roll motion should not be discernible to the test subject (roll rate < 3 degrees per second according to (2)).

Due to these two facts one is normally forced to use a scale factor less than 1 for the moving base. VTI has chosen 0.5 as a suitable factor since the overall system is designed to reproduce 0.4 g accurately. A higher scale factor can be used if the accelerations in the experiment are small or else the safety system will trigger too often.

The roll motion of the simulator is perhaps the most disturbing and nausea-inducing part of the simulator. Thus we have tried to use it as little as possible.
During lane changes within the road width only the lateral motion is activated. The roll motion is used to simulate an overall lateral acceleration based on the vehicle speed and the road curvature. Even with these restrictions the curves should be built up with clothoids (continuously increasing curvature) and S-curves avoided as much as possible. Normally this means that the reconstructions of a race course or a handling test course are not very suitable for simulator drive since they are driven at high speed and contain S-curves and hairpin bends.

Several handling tests may however be performed with success in a simulator of VTI-type. Lane changes (single or multiple) within the capacity of the lateral motion can be reproduced very faithfully and, which may be surprising, the same is true for steady state circle driving up to the limit. Even at the maximal roll angle (24 deg in the moving base!) the driver does not notice that the lateral acceleration produced by the lateral motion is slanted, and the process of losing the grip of the tires either at the front or the rear wheels is felt very easily.

2.5 Nausea in the VTI Driving Simulator

Nausea is not considered to be a great problem in the VTI simulator even if the problem occurs from time to time. Strangely enough it seems to be more frequent among visitors than among test subjects during regular experiments. The reason for this is perhaps that during the experiments the driving is regulated to a high degree with hard manoeuvres and sharp bends occurring very seldom or not at all, while visitors are urged to make quick lane changes and drive fast on a very slippery and curvy road. As mentioned earlier hard general driving on high friction surfaces will reveal weaknesses in all moving bases especially when combining roll and lateral motion. One possibility is of course to decrease the overall scale factor from the current value 0.5 to the 0.2-0.3 region making the problems much less obvious, but it has been considered to be a pity not to utilize the full capacity of the system.

It is very difficult to decide what factors are important for the nausea problems since it occurs not very frequently. The same person can have severe problem on one occasion and then have very little or no problems at another time.

3. RESEARCH APPLICATIONS - CHAPTER 3

Originally designed for vehicle dynamics studies, the VTI driving simulator has mainly been used for driver behaviour research. In a way this is perhaps natural since the ultimate reason for using a simulator is to study the driver and his reactions. Exclude the driver and one could just use the computer program describing the vehicle motion and run a standard digital simulation
of an open-loop manoeuvre. On the other hand changes in the vehicle model are readily discernible in the simulator and there is a potential for simulators in car development. Of course, one cannot expect to solve all problems in simulators but simulator tests can enter between standard simulation programs and building prototypes for field tests cutting costs at this stage.

However, at this point it should be mentioned that the costs for using a simulator can be quite high. The maintenance costs for computers and hardware are quite substantial beside the fact that the large original investment in the beginning must be written off in a limited number of years. All experiments also demand a lot of programming to make the different standard program blocks fit together for that special test. This can be compared with field tests where a lot of time and costs are spent for equipping experimental cars and writing evaluation programs. Normally we have found that most experiments occupy the simulator for one or may be two weeks during the actual experiment but the preparation phase demands one month of qualified programming as an absolute minimum.

3.1 Vehicle dynamics studies

Vehicle design and optimising handling qualities is not a prime interest of VTI, dealing more with general traffic safety problems. Most of the studies in this field have thus been initiated by car manufacturers that want to find out the problems and advantages of using simulator technology for car development. The results are generally proprietary and details cannot be presented here. However, from several aspects we feel that simulator techniques have a lot to offer.

Instantaneous changes of the handling qualities can be made making comparisons easy for the test driver. Speed of changes and the almost unlimited number of objects that can be compared are very strong points in favour of simulators compared to field tests by experimental cars or prototypes. But still it must be remembered that every simulator will always work like some kind of obscuring filter of reality by introducing reduced motion in the moving base, 2-dimensional environment in the visual, artificial noise and sound and so on. Despite these shortcomings the fidelity of the VTI simulator has proved to be high enough for several applications in vehicle handling.

3.2 Driver behaviour studies

The simulator has most of the time been used in experiments where the driver plays the central part. These studies have encompassed effects of alcohol and drugs on driver performance, driver ability to perceive and interpret different layouts, effects of sight deficiencies and of environmental conditions in the cabin like temperature, noise and infrasound. An excellent overview of these can be found in (7), which
covers the period up to the middle of 1989. Several works have been carried out or reported since that time.

One investigation (8) concerned driver fatigue among patients suffering from the sleep apnea syndrome. The simulator was used to evaluate whether objective data of driving performance can be assessed in patients with excessive tendency of falling asleep at the steering wheel. Fifteen male drivers with habitual sleep spells whilst driving were selected among patients with the clinical features of the sleep apnea syndrome. The brake reaction time and deviations from straight road-line were significantly increased when compared to the performance of ten control subjects. Using the driving simulator was found to be a sensitive method to ascertain driving vigilance impairment in quantitative terms. It was also considered to be a valuable method to evaluate the efficiency of treatment in selected patients.

The validation of a system for detecting drops in driver alertness on the basis of steering wheel movements has been carried out lately (5). This system has been developed at the Renault Physiology Laboratory and the validation comprised both simulator and field tests. In the simulator 30 experiments were performed and in 28 of these cases the system was shown to be capable of discriminating between two alertness levels. In 12 of the experiments the test subjects dozed off causing the car to leave the road. This dozing off could have been prevented by the system if the alarm had been actuated. The results obtained in the simulator were checked in real-world driving conditions by two experiments performed on a motorway.

Another study (6) involved a comparison between eye movements in actual and simulated curve negotiation tasks. Using the same measuring equipment in both the field tests and in the simulator the anticipation and perception when negotiating four curves were studied by analysing distribution of eye fixation, time, scan path and number of fixations. The analysis also took into account how well the manoeuvre was performed (speed adaptation, steering wheel movements) and related to driving experience. Although there were some correspondence between field tests and simulator results several important discrepancies were also found. The reasons for these are by no means clear and demand further investigations for clarification.

Recently a study has been conducted in the driving simulator to investigate the influence of use of handsfree telephones on driver behaviour. This study is a part of the DRIVE project V1017 (Bertie).

The driving task was defined by the road (tracking) and by randomly appearing visual stimuli. Two roads differing in difficulty, i.e. in the frequency and sharpness of the curves, were used. The visual stimuli were included to simulate discrete events in traffic.
The subjects had to react to them by braking. Now and then (=randomly) during the experiment the subjects were "disturbed" by a telephone call, and had to perform the telephone task, while they were still driving. The telephone task made demands on both decision making and memorising capabilities.

Because the project now is in the phase of data analysis, the results are not yet available. The working hypothesis to be tested is that the driver behaviour is different when driving and using the telephone simultaneously compared to driving without using the telephone. It is also assumed that such a difference in behaviour is influenced by the level of difficulty of the driving task.

The driver behaviour will be compared and tested in terms of the performance measures speed, position on the road, brake reaction time and time taken to complete the experiment (the distance to be driven was constant). Subjective estimations of workload (TLX method) as well as of the user friendliness and effect assumptions of the handsfree telephone will also be analysed. How the subjects managed the telephone task under the different road conditions is another interesting question that we will try answer from collected data.

4. THE NEW TRYGG HANSA SIMULATOR - CHAPTER 4

4.1 Basic conditions

The conditions for the new TH simulator were as follows

- Should be able accommodate a heavy truck cabin as well as a passenger car.

- It should be possible to simulate the most frequent heavy vehicle combinations in Sweden i.e. truck - full trailer and tractor - semitrailer.

- The technical data should be similar to the original VTI Driving Simulator if possible.

- The simulator must be delivered within a two and a half year period.

Specially the last condition here made it clear that the new simulator must rely heavily upon the earlier design. New development work must be kept down to an absolute minimum, which still means a considerable work. The VTI simulator is a prototype with most of the electronics hardwired making fault finding and commercial duplication very difficult. The process of building a new simulator thus means a necessary update of the old one with electronics constructed and built with CAD.
4.2 Visual system

The new TH simulator will be equipped with the same visual system as the VTI simulator. The geometrical layout will be similar but wide angle projectors with shorter throw distance must be used to avoid that the truck cabin roof obscures the light beams. It is also necessary to use a truck cabin with bonnet or else the driver will see the lower edge of the screen.

4.3 Outer moving base

Still there are big differences between the two simulators. The roll and pitch motions of the simulator are generated differently. The upper part of the simulator is allowed to roll and pitch around a gimbal point positioned under the platform. This is done with two large hydraulic actuators at the rear end of the platform. The result can be studied in figure 1.

Earlier it was considered to be an advantage that the head of the driver is positioned below or at the roll and pitch axes in order to get a correct sign of the acceleration associated with the angular acceleration when pitching or rolling. The VW (3) and VTI simulators were constructed with this in mind but experience gained since then indicates that the rolling and pitching motion should only be performed so slowly that the earlier argument has lost some of its importance. It is interesting to see that the proposed US simulator also utilizes a gimbal point below the platform while the recent MAZDA configuration (4) sticks to the earlier ideas. Putting the gimbal point at a low position will however give a more compact and less costly mechanical system.

Yaw motion is not utilized in neither the VTI nor the new TH simulator. Without yaw motion the systems are considerably less expensive to build. Experiments have shown that the driver easily can detect different yaw velocity delays with only the information from the visual. Thus different yaw handling qualities of passenger cars can be detected in the simulator.

If yaw motion should be incorporated in a simulator of the VTI-type (with long lateral excursions) the allowed yaw angle must be very limited since the lateral rails must always be approximately perpendicular to the longitudinal axis of the car inside. Otherwise there will be great problems when simulating spin-outs with simultaneous yaw motion and lateral accelerations. We have chosen to concentrate on the second alternative here.
4.4 Vibration platform

Beside the outer moving base there is also a vibration platform on which the cabin is mounted. This platform consists of four actuators and two transverse rods. Three of the actuators are mounted vertically to produce vertical vibrations, pitch and roll motion of the car. The remaining actuator is mounted longitudinally to give the transient jerk when braking hard on high friction surfaces. Using only a slow pitch-motion for simulating the braking forces is a major drawback with the original design and is one of the most frequent reasons for complaint among the test subjects.

Since the cabin is mounted in a confined space where the visual screen is quite near the driver the vibration mode must be adjusted. In reality the vibration can be considered as a rotation around a point at infinite distance (horizon line), which in the simulator is translated into a rotation around a point in the screen. This adjustment is necessary for realism. Otherwise the driver will experience the vibrations as much more severe than they really are.

The vibration platform was not included in the original VTI design laid down in the late seventies. The first runs however clearly indicated the need for vibrations without which the road feeling was completely absent. Three vertical actuators together with transverse and longitudinal rods were immediately mounted directly to the car body and this served well for a number of years. Fatigue problems with the weldings and the wish to be able to switch car bodies easily finally resulted in a stable frame on which the different cabins can be bolted.

The stroke length of the actuators in the VTI simulator is ±5 cm allowing a maximum roll angle of 7 degrees. When the car rolls and vibrates simultaneously the vibration platform motion may be saturated. For this reason the stroke length has been increased to ±7.5 cm in the new TH simulator.

4.5 Areas of use

The new TH-simulator will naturally be used in the same way as the VTI-simulator with the further possibility to make heavy truck studies ranging from handling tests to environmental effects inside the cab. It will also be used for training of special categories of truck drivers. For drivers normally involved in the transportation of dangerous goods the cost of using a simulator for training purposes may be justified. This is otherwise the classic problem of driving simulators compared to flight simulators and the reason why there are so few advanced driving simulators around while such flight simulators are used abundantly.
Figure 1: The new TRYGG-HANSA-simulator viewed from
a) behind
b) the side
5 CONCLUSIONS - CHAPTER 5

The interest for using driving simulators has increased sharply during the last three years. In most cases the simulator has proved to be a very effective and safe tool in a variety of studies. It is however important that the prospective user realizes the limitations of the simulator intended for use in the study. Some types of experiments are less suitable since the limitations of the simulator itself are too obvious to the test subject making the interpretation of results difficult.

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Protection Effects of Child Restraints
Experiences from Accidents and Sled Tests with Carry-Cots

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PROTECTION EFFECTS OF CHILD RESTRAINTS - EXPERIENCES FROM ACCIDENTS AND SLED TESTS WITH CARRY-COTS

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1. INTRODUCTION

Each year 53,000 children are injured or killed as car passengers in accidents in the European Community [1]. In the Federal Republic of Germany about 100 children aged from 0-14 years are killed and 12,000 injured annually (Fig. 1). In the 0-3-year age group dealt with in this presentation 30 children were killed as car passengers and 3,000 injured in 1988 [2]. The overall restraint rate for children in cars has levelled off generally at an average of just under 60% (Fig. 2) [3]. A traffic survey [4] showed that the use of special child restraint systems (CRSs) drops with an increase in age, but adults' safety belts are used more frequently instead as the age goes up (Fig. 3). For the above-mentioned age group of infants (0—3 years) an 80% rate of CRS use was recorded in [4]. In the Federal Republic of Germany there is at present the following legal regulation for the use of CRSs: Since 1976 it has been laid down by law that children aged from 0 to 12 years must in principle be seated on the rear seats of cars. Only if all the rear seats are occupied by children may a further child be additionally transported on the front passenger seat. In 1988 this regulation was amended. According to this, a child may sit on the front seat if it is restrained by a CRS of an ECE-R-44-tested type [6]. The international testing regulation for CRSs (ECE-R 44), which will be explained in detail later, has been integrated into national law as the testing regulation in 1988, too. That CRSs which are fitted in cars must be used on the rear seats also applies - even if they are not tested according to ECE-R 44. But since 1989 it has not been allowed to offer for sale CRSs that are not tested according to ECE-R 44. These regulations have thus not yet achieved a mandatory obligation to restrain children in cars; it is therefore still permitted to transport children on the rear seats without CRSs. The injury situation of restrained and unrestrained children will be dealt with below - documented by accident material from the German Automobile Insurers (HUK-Verband) - and a report will be given on the results of sled tests with carry-cots restrained by belts which were carried out by the BAST (Federal Highway Research Institute).
2. INJURIES TO UNRESTRAINED AND RESTRAINED CHILDREN

In the latest study of the HUK-Verband [5] on accidents with children (aged from 0 to 12 years) in cars the injury risk of unrestrained (n = 288) and restrained (n = 865) children was analysed. It was ascertained (Fig. 4) that 51.4% of the unrestrained children sustained MAIS 1-6 injuries; the proportion of the MAIS 2-6 injuries was 10.1%.

In the case of restrained children, 17.3% sustained MAIS 1-6 injuries; the proportion of MAIS 2-6 injuries was only 1.4%. The share of serious and fatal injuries (MAIS 3-6) for restrained and unrestrained children shows Fig. 5 (3.5% unrestrained, 0.5% restrained); the risk of sustaining serious/fatal injuries was seven times higher for children who were not restrained by CRSs than for restrained children and if the proportion of fatal injuries (MAIS 6) is compared, the risk of unrestrained is 3.5 times higher.

The individual injuries (AIS 1-6) for unrestrained children to the different parts of the body (all accident types including roll-over) are presented in Fig. 6. If the three most frequent individual injuries are arranged in order the following list of priorities emerges for unrestrained children:

1. Head injuries: AIS 1-6 (55.4%), AIS 2-6 (11.5%)
2. Injuries to the arms (21.6%) and to the legs (21.0%)
3. Bruises and abrasions in all regions of the body (14.9%)

Neck injuries to the unrestrained children have a frequency of 5.4%, but only AIS 1 injuries were found in the study material up to now.

The individual injuries to restrained children are presented in Fig. 7. If the three most frequent individual injuries are arranged in order the following list of priorities emerges:

1. Head injuries: AIS 1-6 (60.4%), AIS 2-6 (1.4%)
2. Neck injuries (15.3%)
3. Abdominal injuries (13.9%)

The injuries to these three parts of the body dominate, however, not only with regard to frequency but also when the severity of the injuries is taken into consideration.

The relative frequency of neck injuries to children observed in the HUK-Material [13] is also confirmed in the international literature [14, 15, 16, 17, 18, 19]. Cases of tetraplegia in infants caused by accidents, in spite of the use of a CRS, have attracted considerable
attention in the Federal Republic of Germany in recent times. In the case of forward-facing CRSs, the infant's relatively large head mass and the safety requirements of ECE-R 44 can obviously lead to excessive loading on the baby's neck resulting in serious neck injuries. In general more biomechanical experience is needed to assess the injury mechanism.

3. TESTING REGULATIONS FOR CHILD RESTRAINT SYSTEMS

Since 1981 ECE-R 44 has been applied for testing child safety seats. This regulation was expanded in 1986 and 1988 and now covers the regulations for testing child restraint systems for children of all ages, i.e. from carry-cots for babies to seats for children up to the age of 10-12 years.

The systems are divided into the following weight classes:

<table>
<thead>
<tr>
<th>Group</th>
<th>Weight</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>&lt; 10 kg</td>
<td>0 - 9 months</td>
</tr>
<tr>
<td>I</td>
<td>9 - 18 kg</td>
<td>9 months - 3 years</td>
</tr>
<tr>
<td>II</td>
<td>15 - 25 kg</td>
<td>3 years - 6 years</td>
</tr>
<tr>
<td>III</td>
<td>22 - 36 kg</td>
<td>6 years - 10 years</td>
</tr>
</tbody>
</table>

Every CRS must be tested with dummies of the lower and upper age class given. The test is oriented to a head-on car impact of 50 kph. Rearward-facing systems also have to be tested with a reverse impact speed of 30 kph. The deceleration impulse is also specified [6]. The aim of this test is to prove that the child seats remain securely anchored to the car seat by the belts and that the children restrained by belts have a certain "survival room" in the event of an impact; i.e. a space is specified which the child's head must not leave when an impact occurs. The geometrical measurements are:

- horizontally max. 550 mm
- vertically max. 800 mm

related to the pivotal point of the back of the seat (Fig. 8).

There are no criteria for the dummies' head protection, neck protection or abdomen protection; there is only a chest criterion. The resultant chest acceleration must be less than 55 g, and the vertical chest acceleration must be less than 30 g.

The test of the universal systems takes place on a sled or a trolley on which a standard rear seat is mounted. The design and rigidity of this standard rear seat
corresponds to an "average" car seat [6]. The belt geometry described in ECE-R 44 is different from real car’s belt geometry.

4. THE SAFE TRANSPORT OF CHILDREN IN CARS

For the very smallest children prams with removable carry-cots are on the market to an increasing extent in Germany nowadays. These carry-cots can be placed on the rear seat of the car without having to transfer the child, while the "chassis" of the pram can be folded up and carried in the boot. To fasten these carry-cots in the car several different kinds of belt systems are available (Figs. 9a and 9b). Crash tests with this kind of carry-cot belt systems will be reported on later.

Another possibility of transport, widespread in Sweden, is the use of rearward-facing child seats on the front passenger seat (Fig. 10). In this case it is important to ensure that the seat is correctly fastened in place using the 3-point belts which are part of the car’s standard fittings. There are further rearward-facing seats which can be inclined, and parents tend to adjust the seats in a nearly horizontal position when children are asleep. This can, if the worst comes to the worst, result in there being no large area to support the baby from behind in the event of an impact, so that the shoulder belts alone restrain the baby; it is also possible for the child to slip out. In Sweden the experience with rearward-facing systems of this kind in Group 0 [7, 8, 9] has so far been very positive.

For children in Group I, i.e. aged from about 1-3 years, there are child seats of a wide variety of designs on the market. They can be schematically divided up into four basic systems and are presented in Fig. 11 [10]. Up to now throughout Europe about 200 different CRSs have been officially tested and about 100 CRSs are at present on sale, the products of altogether some 50 manufacturers [1].

In addition to larger rearward-facing child seats, three different forward-facing systems are in use: child safety seats with separate 4-point belts, child seats with an impact shield and child seats which use the car’s 3-point seat belts to restrain the children.

Tests of different CRSs (head-on collision with 50 kph and rear-end impact with 30 kph) for the age Group I, each with P 3/4 and P 3 dummies with additional neck and abdomen sensors which were recently published in [10, 20] show that:

- the largest frontal head displacement with CRSs was measured when 4-point belt systems were used (the combined effect of the slack of two belts),
- the greatest loading on the neck also occurred in CRSs using 4-point belt systems (systems with a
3-point belt and impact shield showed clearly lower values,
- the chest acceleration was between 53 g for 4-point belt systems and 37 g for CRSs with an impact shield, thus in some cases only just below the loading limit of 55 g,
- the abdominal loading, too, (caused by the central buckle) was highest for CRSs with 4-point belts.

All in all, it can be stated that rearward-facing systems and systems with an impact shield are the safest in the event of a 0° head-on impact. For impact directions at an angle very many CRSs show weaknesses, and in the case of a rear-end collision large head displacements have to be expected when rearward-facing systems are used without additional fixation [10].

It is not intended here to go into child restraint systems suitable for the age Groups II and III. One reason for that is the observed relatively low injury severity of older children in the HUK-material (Fig. 12).

5. RESULTS OF CRASH TESTS WITH CARRY-COTS

According to the latest supplement to ECE-R 44, carry-cots with the proper belts can be tested as restraint systems for children in Group 0. An appropriate study was carried out by the BASt [11, 12]. Eleven trolley tests were performed with the dummy type P O (British standard) and P 3/4 (TNO). The chest acceleration was measured and the head displacement was ascertained by using photos recorded on film.

In the tests the combinations of 6 different commercially available carry-cots and 4 different harness systems (two of which, however, were practically identical in design) were tested. The crash tests at 50 kph were performed only head-on using a trolley on which two standardized seats in accordance with ECE-R 44 were mounted. It was assumed that the lower requirements of the test in reverse direction at 30 kph could then be regarded as having been fulfilled. It was possible to observe the deceleration specified by ECE-R 44 within the given limits. So two systems - carry-cot and belt - could therefore be investigated during each crash test. Head and trunk acceleration measurements were made and recorded on the P-3/4 dummy. Without going into detail about the various models of carry-cots and the efficiency of the different harness systems - the following points can be noted:

In all tests using the P-0 dummy, the only assessment criterion demanded in ECE-R 44 (horizontal head displacement) was satisfied, with displacements lying below the limit value of 550 mm. In all tests using the P-3/4 dummy, however, one of the limit values - head displacement or chest acceleration - was exceeded.
In accordance with ECE-R 44, such systems can only be regarded as being satisfactory if they maintain the permissible limit values for the upper and lower age limits. With a strict interpretation of the regulation, therefore, all the harnesses and carry-cots in the various test combinations failed.

If we differentiate slightly between the test results, depending on whether the harnesses or the carry-cots failed, the following general points can be made for the carry-cots:

The majority of carry-cots are obviously not specially designed to withstand the high stresses during an accident. Only one of the carry-cots tested - shown in Fig. 13 - exhibited special constructional measures designed to withstand the stresses occurring in an impact. These measures include being able to place additional padding inside the carry-cot which, although restricting the freedom of movement of the baby, also allows the baby to participate in the deceleration of the vehicle from an early point. In the other carry-cots, the babies have no direct contact with the side wall of the carry-cot. As a result, the baby does not participate in the deceleration of the vehicle in the event of a collision, but is first subjected to a period of free movement which results in the baby colliding with the side wall of the carry-cot with a considerably higher impact. In certain cases, the carry-cots are not designed sturdily enough to withstand the collision, so that the side walls, which are sometimes only made by pasteboard (Fig. 14) collapse and the baby is stopped suddenly by the harness. Where harnesses are used which have two separate belts running over the carry-cot, the baby is restrained at the neck and knees. Although no measuring values are available, severe injury in the area of the neck must be expected in this case.

In one of the carry-cots tested, practically unpadded steel loops were let into the side walls underneath the cover material at the level of the baby's head (Fig. 15). These steel loops represent an exceptionally high risk of injury. This type of carry-cot must be considered totally unsuitable. The ECE-R 44, however, contains no head injury criterion.

The results for the harnesses used were rather better than those for the carry-cots, although here again system-specific benefits and disadvantages were discovered. Two special static harness systems are available on the market which can be installed on the rear seat instead of the three-point seat belt to restrain the carry-cot. The main difference between these two systems is the positioning of the belts. The one harness system has two belts which pass around the carry-cot and they are fastened with two buckles above
the baby. The other system has one central buckle for both belts. Once installed, both harness systems are easy to use.

The 2-buckle system has the disadvantage that as the side wall of the carry-cot collapses - as already described - the baby is constricted around the neck and legs. In the system with the central buckle there is a danger that the unfavourable centre of gravity of the baby (relatively heavy head) may cause the carry-cot to twist out of the harness, thereby permitting an excessive displacement of the head.

Another harness system which is available on the market consists of an angular frame with two belts which is installed on the rear seat using the 2-point or 3-point automatic seat belt (Fig. 16). This makes it easier to transfer the carry-cot with harness from one vehicle to another. This system is also easy to use. However, it also has one central fastener in the middle, so that the disadvantages described above of the carry-cot twisting out of the harness apply here, too. Added to this is the fact that the seat belts of the car and carry-cot belts can both have a belt slack, so that the displacement also becomes greater.

All the belts tested were completely undamaged even after several tests. The fasteners could be opened without difficulty on all the belts after the tests.

ECE-R 44 defines the safety of child restraint devices only for 0° collisions. In the actual accident statistics, however, oblique collisions are encountered far more frequently. In such cases it must be feared that many carry-cots could slip out of the harnesses completely and be catapulted around inside the car.

6. SUMMARY

By incorporating ECE-R 44 into the German Road Traffic Act the belting rate for children aged 0-3 years in cars with special CRSs was raised to about 80%. In spite of this, 30 children in this age group are killed and 3,000 are injured as car passengers in West Germany annually.

The accident material of the German Automobile Insurers has furnished evidence of the effectiveness of CRSs. It shows that over 80% of children transported in CRSs remain uninjured after an accident, while this holds true for only just under 50% of the unrestrained children. The risk of severe and fatal injuries is about 7 times greater for unrestrained children. Regarding the remaining risks of restrained children head injuries predominate, but also serious injuries to the neck and abdomen/pelvis occur. The dummies
described in ECE-R 44 for testing CRSs have no corresponding measuring sensors, and critical biomechanical loadings for children are practically unresearched.

For the ECE-R-44-tested carry-cots held in place by belts, the following results can be noted:

Pram carry-cots are unsuitable

- if their walls are too soft (pasteboard) and break when jolted by the accident,
- if their side walls are unpadded,
- if hard and angular hoops are let into the side walls.

Suitable carry-cots have sturdy, padded sides and are supplied with a sleeping bag which is firmly held in place.

None of the three different belt systems which underwent testing according to ECE-R 44 failed. But it seems possible with all the belt systems for the child to slip out in the event of an angular impact.

As far as the applicability of ECE-R 44 for Group 0 is concerned, the following points can be made:

- A head protection criterion would appear to be necessary, as the head of the test dummy always struck the side wall of the carry-cots. The kinematic criterion alone (head displacement within given limits) is not sufficient.
- The criterion vertical acceleration of the chest < 30 g can be omitted for lying babies.
- An investigation of the lateral movement of the carry-cots in the harness during angled impacts would appear to be necessary.
- It should be examined whether a rear-end collision test - which is necessary for rearward-facing baby seats - is necessary for carry-cots or not.

7. REFERENCES


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List of figures:

Fig. 1 Children killed and injured as car passengers in the Federal Republic of Germany

Fig. 2 Usage rate of child restraint systems in the Federal Republic of Germany

Fig. 3 Usage rate of child seats and 3-point belts vs. age in the Federal Republic of Germany

Fig. 4 MAIS distribution of unrestrained and restrained children

Fig. 5 Injury severity of unrestrained and restrained children

Fig. 6 Injury distribution of unrestrained children

Fig. 7 Injury distribution of restrained children

Fig. 8 Test seat acc. ECE-R 44

Fig. 9 a,b Belt systems for carry-cots
   a: one-buckle system
   b: two-buckle system

Fig. 10 Rearward-facing system

Fig. 11 Different child restraint systems for ECE-group I (9 months - 3 years)

Fig. 12 Injury severity vs. age, restrained children

Fig. 13 Carry-cot with sufficient energy absorption and stiff shell

Fig. 14 Carry-cot with broken pasteboard shell after test

Fig. 15 Carry-cot with steel loops and broken side wall

Fig. 16 Belt system with angular frame and carry-cot with fixed sleeping bag
Source: Statistisches Bundesamt

Fig. 1 Children killed and injured as car passengers in the Federal Republic of Germany

<table>
<thead>
<tr>
<th>Month/Year</th>
<th>Total</th>
<th>CRS</th>
<th>3-point belt</th>
</tr>
</thead>
<tbody>
<tr>
<td>9/84</td>
<td>32</td>
<td>24</td>
<td>8</td>
</tr>
<tr>
<td>3/85</td>
<td>36</td>
<td>26</td>
<td>10</td>
</tr>
<tr>
<td>9/85</td>
<td>31</td>
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</tr>
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</tr>
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</tr>
<tr>
<td>3/87</td>
<td>55</td>
<td>31</td>
<td>24</td>
</tr>
<tr>
<td>9/87</td>
<td>49</td>
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</tr>
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<td>3/89</td>
<td>58</td>
<td>30</td>
<td>25</td>
</tr>
<tr>
<td>9/89</td>
<td>59</td>
<td>29</td>
<td>34</td>
</tr>
</tbody>
</table>

CRS - Child Restraint System

Fig. 2 Usage rate of child restraint systems in the Federal Republic of Germany
**Fig. 3** Usage rate of child seats and 3-point belts vs. age in the Federal Republic of Germany

<table>
<thead>
<tr>
<th>MAIS</th>
<th>Unrestrained (n = 288)</th>
<th>Restrained (n = 865)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>48.6%</td>
<td>83.7%</td>
</tr>
<tr>
<td>1</td>
<td>41.3%</td>
<td>15.9%</td>
</tr>
<tr>
<td>2</td>
<td>6.6%</td>
<td>0.9%</td>
</tr>
<tr>
<td>3</td>
<td>1.7%</td>
<td>0.1%</td>
</tr>
<tr>
<td>4/5</td>
<td>1.1%</td>
<td>0.2%</td>
</tr>
<tr>
<td>6</td>
<td>0.7%</td>
<td>0.2%</td>
</tr>
<tr>
<td>Total</td>
<td>100.0%</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

**Fig. 4** MAIS distribution of unrestrained and restrained children
Injury severity MAIS 3 - 6
Unrestrained and restrained children

Fig. 5 Injury severity of unrestrained and restrained children
Unrestrained children
0 - 12 years
All impact areas

<table>
<thead>
<tr>
<th></th>
<th>AIS 1</th>
<th>AIS 2</th>
<th>AIS 3-5</th>
<th>AIS 6</th>
<th>Rel.prop.of injuries Basis:148 inj.-100%</th>
</tr>
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<tbody>
<tr>
<td>Head</td>
<td>65</td>
<td>11</td>
<td></td>
<td>6</td>
<td>55.4%</td>
</tr>
<tr>
<td>Neck</td>
<td>8</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>5.4%</td>
</tr>
<tr>
<td>Shoulder</td>
<td>11</td>
<td>1</td>
<td>--</td>
<td>--</td>
<td>8.1%</td>
</tr>
<tr>
<td>Chest</td>
<td>11</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>7.4%</td>
</tr>
<tr>
<td>Arms</td>
<td>28</td>
<td>3</td>
<td>1</td>
<td>--</td>
<td>21.6%</td>
</tr>
<tr>
<td>Abdomen/Pelvis</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>4.1%</td>
</tr>
<tr>
<td>Legs</td>
<td>23</td>
<td>8</td>
<td>--</td>
<td>--</td>
<td>21.0%</td>
</tr>
<tr>
<td>Bruises/Abrasions</td>
<td>21</td>
<td>1</td>
<td></td>
<td></td>
<td>14.9%</td>
</tr>
</tbody>
</table>

Fig. 6 Injury distribution of unrestrained children

Restrained children
0 - 12 years
All impact areas

<table>
<thead>
<tr>
<th></th>
<th>AIS 1</th>
<th>AIS 2</th>
<th>AIS 3-5</th>
<th>AIS 6</th>
<th>Rel.prop.of injuries Basis:144 inj.-100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>80</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>60.4%</td>
</tr>
<tr>
<td>Neck</td>
<td>20</td>
<td>--</td>
<td>2</td>
<td>--</td>
<td>15.3%</td>
</tr>
<tr>
<td>Shoulder</td>
<td>12</td>
<td>2</td>
<td>--</td>
<td>--</td>
<td>9.7%</td>
</tr>
<tr>
<td>Chest</td>
<td>13</td>
<td>1</td>
<td>--</td>
<td>--</td>
<td>9.7%</td>
</tr>
<tr>
<td>Arms</td>
<td>13</td>
<td>2</td>
<td>--</td>
<td>--</td>
<td>10.4%</td>
</tr>
<tr>
<td>Abdomen/Pelvis</td>
<td>16</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>13.9%</td>
</tr>
<tr>
<td>Legs</td>
<td>11</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>7.7%</td>
</tr>
<tr>
<td>Bruises/Abrasions</td>
<td>4</td>
<td>--</td>
<td></td>
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<td>2.8%</td>
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Fig. 7 Injury distribution of restrained children
Fig. 8 Test seat acc. ECE-R 44

Fig. 9 a,b Belt systems for carry-cots
a: one-buckle system
b: two-buckle system
Fig. 10  Rearward-facing system
Fig. 11  Different child restraint systems for ECE-group I (9 months - 3 years)
<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Injury severity MAIS</th>
<th>No. Total</th>
</tr>
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<tr>
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<td>0 1 2 3 4/5 6</td>
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<tr>
<td>0</td>
<td>77 10 2 1 1</td>
<td>91</td>
</tr>
<tr>
<td>1</td>
<td>159 24 1 1</td>
<td>185</td>
</tr>
<tr>
<td>2</td>
<td>132 28 2 1</td>
<td>163</td>
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<tr>
<td>3</td>
<td>98 16 1</td>
<td>115</td>
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<tr>
<td>4</td>
<td>74 12 2</td>
<td>88</td>
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<tr>
<td>5</td>
<td>59 13</td>
<td>72</td>
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<tr>
<td>6</td>
<td>39 8</td>
<td>47</td>
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<tr>
<td>7</td>
<td>26 8</td>
<td>34</td>
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<tr>
<td>8</td>
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<tr>
<td>9</td>
<td>13 2</td>
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<td>13</td>
</tr>
<tr>
<td>12</td>
<td>4 2</td>
<td>6</td>
</tr>
<tr>
<td>Total</td>
<td>715 137 8 1 2 2</td>
<td>865</td>
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<tr>
<td>%</td>
<td>82.7 15.9 0.9 0.1 0.2 0.2</td>
<td>100.0</td>
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</table>

Fig. 12  Injury severity vs. age, restrained children
Fig. 13 Carry-cot with sufficient energy absorption and stiff shell

Fig. 14 Carry-cot with broken pasteboard shell after test
Fig. 15 Carry-cot with steel loops and broken side wall.

Fig. 16 Belt system with angular frame and carry-cot with fixed sleeping bag.