Infrastructure design & road safety

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Lectures

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The Road safety phenomenon. Fred Wegman. SWOV. The Netherlands.

Road design and design standards. Pim Slop. SWOV. The Netherlands.

Road classification. Pim Slop. SWOV. The Netherlands.

Methods for investigating the relationship between accidents and road design standards. G. Maycock & I. Summersgill. Transport Research Laboratory. England.

The relationship between speed and accidents. G. Maycock. Transport Research Laboratory. England.

Design of motorways and rural roads with special emphasis on traffic safety. Prof.dr. -Ing. habil. Ruediger Lamm. Institute for Highway and Railroad Engineering. Germany.

Urban streets. Kenneth Kjemtrup. The Danish Road Directorate. Denmark.

Roadside safety. Fred Wegman. SWOV. The Netherlands.

Black spot approach. Pim Slop. SWOV. The Netherlands.

Low-cost engineering measures. Pim Slop. SWOV. The Netherlands.

Vulnerable road users. Pim Slop. SWOV. The Netherlands.

Road signs, markings and working zones. Kenneth Kjemtrup. The Danish Road Directorate. Denmark.

OECD WORKSHOP ON
"*INFRASTRUCTURE DESIGN AND ROAD SAFETY*"

15-18 November 1994, Prague (Czech Republic)

INTRODUCTORY STATEMENT

by Burkhard HORN
OECD Road Transport Research Programme

This Workshop during this week is the second one we are holding here in Prague in the framework of OECD's Road Transport Research Programme and the Workshop Series for Central and Eastern European countries. We had a very successful one about one month ago on *Winter Maintenance*. I should like to thank the Ministry of Transport, the Highway Authorities and Mr Trcka, from Pragoprojekt, for the invitation and the preparation and organisation. We are especially grateful to the Dutch Road Safety Foundation (SWOV) -- Mr Wegman -- and the Commission of the European Communities who in part financed this event.

It is obvious: the better the infrastructure, the more efficient the traffic and in principle the higher the traffic safety. The concept and key elements of safe infrastructure are well known. However the special situation in CEEC's and the newly compelling demands for environmentally friendly designs impose thoughtful approaches and, especially, cost-efficient planning and implementation.

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The Road Transport Research Programme of the OECD, with headquarters in Paris, is supported by twenty-five governments of Europe, the United States, Canada, Australia, Japan, New Zealand and Mexico.

The Programme fosters the strategic dialogue between Member countries to propose responses to the transport challenges beyond 2000. While focusing on concrete and well-defined research requirements, the Programme initiatives attempt to address the compelling socio-economic realities that drive Member governments' road and road transport policies in a multimodal context approach taking full account of the industry's and the private sector concerns and needs.

The Programme's mission is to:

- Enhance effective and innovative research through international co-operation and networking;
- Undertake joint policy analyses and prepare technology reviews of critical road transport issues;
- Pursue further the worldwide exchange of scientific and technical information in the transport sector and promote road technology transfer between and within OECD Member and Non-member countries.

Technology transfer and information exchange take place through two databases -- The International Road Research Documentation (IRRD) scheme to provide worldwide information on scientific responses and current research programmes and the International Road Traffic and Accident Database (IRTAD) to collect and disseminate comparable aggregate data on a regular basis for twenty OECD Member and associate countries. We welcome all the countries present here to participate.

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Taking into account the experience acquired in the past twenty-five years by the OECD/RTR Programme, the Steering Committee for the Programme, which is also its Governing Board, decided to propose joint initiatives towards Central and East European Countries and New Independent States concerning technology transfer and exchange of scientific and technological information in the field of road and road transport. A series of fourteen CEEC Workshops has been implemented.

The concrete aims of these initiatives are to provide state-of-the-art knowledge and practices applicable to prevailing national contexts and conditions; to identify tools, means and strategies for improvements; to recommend plans, organisational frameworks and implementation procedures; and to promote feedback and evaluation of actions taken. Annex A of my statement provides you with a list of past and planned Workshops, including the respective responsibilities of the countries.

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Road design is a particularly difficult subject from the point of view of traffic safety.

Since the beginning of road safety research, there have been two schools: should the road environment be adapted to man, i.e. the road user, or should the road user adapt his behaviour to road conditions? However, it is very difficult, in all practical cases, to separate, assess and quantify with satisfying validity the contribution of individual and situational conditions leading to accidents.

Research and experience have provided safety principles that are now widely applied. These concern inter alia:

- horizontal and vertical alignment;
- cross-section and roadside layout (and obstacles);
- pavement surfaces;
- access control; intersections and interchanges;
- by-passes;
- identification and treatment of hazardous road locations.
- construction and maintenance zones;

- road marking, delineation and signing systems;
- protection of vulnerable road users; climbing lanes;
- railroad-highway grade crossings.

It is essential to note that from the road safety point of view access controlled motorways of modern design standards constitute the safest and most efficient routes with substantially lower accident risks when compared to other road infrastructure.

Thanks to a number of outstanding professionals, you will receive a rather comprehensive picture of good practice and current expertise. We hope that this will help you in your day-to-day work and contacts in the future.

To conclude, road infrastructure and road transport development is one of the key elements both in the operation of emerging market economies and their European integration.

May I thank all the authors and rapporteurs for their important contribution and efforts as well as participants for their interest in the OECD/RTR Workshop.

Thank you for your attention.

ANNEX A
SUMMARY TABLE OECD WORKSHOPS FOR CENTRAL AND EASTERN EUROPEAN COUNTRIES

Code	Title	Description	Location & Date	Lead Sponsors
A1	Bituminous Materials for Road Construction and Maintenance	Proceedings available	Budapest 7-10 Dec. 1993	OECD/EAPA
A2	Road Aggregates	Proceedings in preparation	Bulgaria 25-28 May 1994	F
A3	Road Rehabilitation and Strengthening	Proceedings in preparation	Arad (Romania) 25-29 April 1994	F/US
A4	Road Maintenance Management	Proceedings in preparation	Warsaw 26-30 Sept. 1994	DK/S
A5	Road Winter Maintenance	Proceedings in preparation	Prague 18-20 Oct. 1994	B
A6	Management of Existing Bridges	Proceedings in preparation	Kaunas, Lithuania 12-16 Sept. 1994	DK
B1	Accident Data System	Final report in preparation	Jurmala, Latvia 16-20 May 1994	SF
B2	Education and Training of Drivers	Final report in preparation	Warsaw 3-5 October 1994	S,(D)
B3	Infrastructure Design and Road Safety	Programme available	Prague 15-18 Nov. 1994	NL
B4	Children's Safety/Education	Mandate prepared	Cracow, Poland 1995	NL
B5	Automobile Insurance and Traffic Safety	Programme in preparation	Russia (?), 1995	SF
B6	Vehicle Inspection: Policy Development and Strategy	Programme available	Budapest 12-15 December 1994	D
C1	Roads and Road Transport in Black Sea Countries: Needs and Future Actions	Programme available	Istanbul 23-25 November 1994	TR/D/US
C3	Environmental Impact Evaluation of Road Infrastructure	Programme in preparation	Prague 7-10 Feb. 1995	SF/CH

THE ROAD SAFETY PHENOMENON

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1. Introduction

Central and East European Countries (CEECs) are faced with the enormous task of implementing political, economic and social changes in converting their centrally controlled planned economy to a market economy. Transport and infrastructure are of vital importance in bringing about these changes and achieving economic growth. Economic growth will lead to increased prosperity and to a rise in the number of private cars owned. Once economic growth is established, this will also result in increased mobility: more transportation of goods, including by road, and higher mileage by private motorists. Unless the road system is expanded and the quality of the existing road system improved, major problems will arise: capacity problems that lead to less efficient use of the infrastructure and hence to economic losses and problems relating to nature and the environment, various difficulties (such as through traffic passing through small towns and villages, city centres congested with cars) and more accidents and casualties.

If it is assumed that the recent political and economic changes in CEECs result in (tremendous) economic growth and thereby in a further increase in mobility (a 'catching up' action), then extra effort will be needed to decrease the fatality rate. The extent to which this succeeds will determine the developments in road safety in CEECs. However, present indications give cause for concern. The number of casualties has risen in the last few years in the various countries and CEECs already score badly on various counts (number of casualties per inhabitant and per kilometre), as can be seen in Table 1.

In this contribution it is assumed that this is in fact the case. Without in-depth analysis of road safety and of the developments that affect it in the countries mentioned and without knowledge about their administrative system and administrative culture, one should not be tempted to formulate recommendations as to how road safety can best be improved in these countries. It is possible, however, to indicate the extent to which the policy pursued in highly motorised countries has helped the improvement of road safety. For the most part this will need to be a qualitative evaluation. It is also possible, using present knowledge, to indicate what could have happened in the past in western countries in order to achieve better results. Both of these aspects are examined: what policy has been pursued in highly motorised countries, especially in the field of infrastructure, and what is the result of this and also what could have happened that would have produced better results. CEECs could then judge for themselves what is applicable for them.

2. The road safety phenomenon

Let us look at an account of a road accident at random (Wegman, Mathijssen & Koornstra, 1991). An 18 year old youth has just passed his driving test. One Saturday night he is driving his friends home from a disco. The teenager has recently bought a second-hand car. The way home takes them over a winding dike beside a river. It is raining. The teenager misjudges a

	Fatalities per 100,000 population	Fatalities per 10,000 motor vehicles
Estonia	29.4	-
Hungary	20.5	3.3
Latvia	32.9	-
Lithuania	29.1	-
Poland	20.7	10.9
Russian Federation	30.4	13.4
Czech Republic	15.6	5.4
Austria	19.9	4.0
Belgium	18.7	3.9
Denmark	11.8	2.9
Finland	12.6	2.8
France	18.5	3.9
Germany	14.2	2.6
Italy	14.0	2.4
Netherlands	8.5	2.0
Norway	7.6	1.5
Spain	22.6	5.6
Sweden	8.7	1.7
Switzerland	12.4	2.1
United Kingdom	8.2	1.6
Australia	12.2	2.0
Japan	11.6	2.2
New Zealand	18.9	2.9
USA	16.4	2.2

Table 1. *Fatalities (within 30 days) per 100,000 population (personal safety) and per 10,000 motor vehicles (road traffic safety) for highly motorized countries (source IRTAD) and Central and East European countries (1991)*

bend. He is driving too fast so he cannot adequately correct for the bend. The car drives into the river. Because the youths are not wearing a seat belt, they are thrown out of the car and drown. The following morning a passer-by discovers the accident.

Cause? A young, inexperienced driver, not wearing a seat belt, driving at night in the rain along a road without a barrier, an unexpected sharp bend, bald tires? All of these factors could have contributed to the accident and to the outcome. Often a critical combination of circumstances is involved (OECD, 1984). Pointing to one single cause, finding one culprit for an accident, does not do justice to the complex reality and - unnecessarily - limits the real opportunities to prevent accidents. Research reports in the United States and the United Kingdom (cf. Rumar, 1985) have concluded that 95% of accidents are due to human error, 30% result from faults in road-design and 10% are the result of mechanical defects (Figure 1).

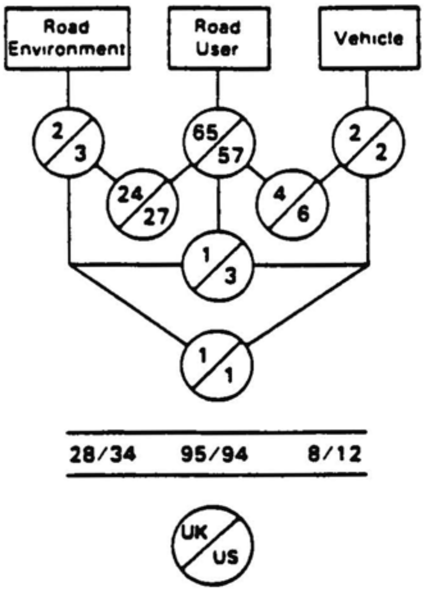


Figure 1. Percent contributions to traffic crashes as obtained in British and US in-depth studies (Rumar, 1985)

One conclusion that is sometimes drawn from this is that education (information, police enforcement, training) is the most important way of preventing accidents. This conclusion is erroneous and researchers have warned often enough about drawing such a conclusion. Is it not the case that road improvements, for instance, are intended to prevent human error? Information about the 'single' cause of accidents does not logically lead to a conclusion about the most effective way of preventing accidents, not counting the cost of measures. It is also possible to draw erroneous conclusions if one relies on police reports in which the question of guilt is settled. One of the people involved in the accident has always violated the law in some way: traffic regulations are so strict. However, this does not say anything about the most effective or efficient way of preventing an accident.

It is advisable to use a phase-model of the accident process when analysing road accidents and formulating measures. Figure 2 shows an example of a simplified model.

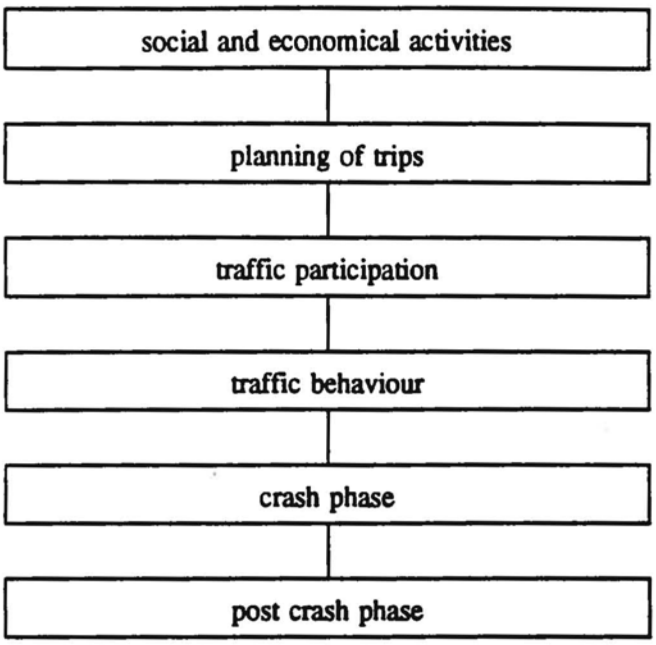


Figure 2. Phase model of the accident process.

There are many opportunities to intervene in this process. The earlier the intervention, the more structural and effective it will be. In the end road users themselves will have to prevent accidents and behaviour always plays a part in this. Others, though, (road authorities, road safety organisations etc.) can influence circumstances such that the risk of human error is reduced. Preventing accidents or lessening the seriousness of the outcome is not only the responsibility of the individual road user but also of collective decision makers (authorities, private organisations, industry etc.).

Furthermore, people should realise that when it comes to decisions about road infrastructure and about the vehicles that use it, there are more arguments involved than road safety considerations alone; these include physical planning and land-use policy, transport and traffic policy, environmental considerations, public health policy, etc (OECD, 1984 and 1994). This means that road safety is just one of the criteria used in decisions of this kind. It very often happens that road safety is not considered to be the main objective, though decisions are made that may have consequences for road safety. Road safety is one facet of these other areas of policy. This may mean that insufficient or no importance is attached to road safety, something that can happen consciously or unconsciously (Wegman & Oppe, 1988).

3. Developments in road safety in CEECs

Representatives from the countries themselves have made revealing statements: "In Russia, the problem of road safety is currently of vital importance. According to statistics, almost all absolute and relative indices of accident rates have been increasing" (Federov, et al., 1993). The Road Safety Plan of Hungary states: "Compared to earlier national data and to international data, the number of people who have died or been injured in road accidents has increased, while discipline in traffic and observance of regulations are at their worst level ever".

A number of reports have been written recently that give an indication of the road safety problems in CEECs. For example, the World Bank and the European Community commissioned an initial survey in Hungary, Poland, Bulgaria, Rumania, the Czech Republic and Slovakia (e.g. Gerondeau, et al, 1992 and 1993). The Nordic Road Traffic Safety Council has also issued a report on the road safety situation in the Czech Republic, Slovakia, Hungary and Poland (NRTSC, 1992). The Technical Research Centre VTT from Finland has published a study on road safety in Estonia, Latvia and Lithuania (Segercrantz, 1992). In all of these reports an analysis is given of the developments in road safety, the conclusion is drawn that these countries compare unfavourably on an international scale and it is anticipated that there are many opportunities to improve the situation. At the end of 1992, the OECD organised a seminar on 'Technology transfer and diffusion for Central and East European Countries' in the area of roads and road transport (OECD, 1993). One of the themes of this seminar was road safety and the major conclusion drawn was that "Traffic safety is a major concern and targeted and integrated actions should be taken as soon as possible in order to reduce drastically the high economic costs incurred by road traffic accidents".

In order to give an indication of the economic scale of the problem, reference can be made to estimates prepared by the World Bank expert group. This group estimated that at present between 1 and 2% of the GNP is lost through costs incurred by road accidents.

The developments in the field of road hazard do not show a steady, continuous pattern. Figure 3 shows the developments for three countries, with no recognisable trend.

Figure 3. Fatalities in Hungary, Poland and the Czech Republic, 1975-1992.

The political and economic changes at the end of the 1980s seem to be expressed also in terms of a growth in the annual number of road accident fatalities. Of course, indications can be given to explain this phenomenon, which can also be found in the literature: a rapid growth in the number of vehicles, many new and inexperienced drivers on the road, many western new and second hand cars driving at relatively highs speeds on inadequate and insufficiently maintained roads, much driving under the influence of alcohol in situations where there is little police enforcement and a poorly equipped police force, etc. These are possible explanations, but scientifically supported evidence is not available.

It is furthermore striking that, in a number of countries, the growth in road hazard has come to a halt. There are even countries where the 'war seems to be won'. Is the drop in road hazard in countries such as Hungary and Poland the herald of a favourable development, or is there question of a temporary favourable development which will soon revert? In order to be able to answer this question, it is useful to consider what developments have occurred in this field in highly motorised countries. If these developments can also be applied to Central and Eastern Europe, then predictions can be made for these countries on the same basis. However, it is risky to make statements about anticipated changes, particularly for the future. Reason enough to say something about the past in highly motorised countries, but not to be too eager to make statements about future road hazard developments for countries in Central and Eastern Europe. Nevertheless, lessons can be learnt!

4. More mobility, yet fewer traffic fatalities.

In various papers my colleagues Koornstra and Oppe have successfully modelled the developments of road fatalities based on long term developments in traffic growth (motorised kilometres) and in fatality rates (road deaths per distance of travel). The so-called logistic function, which is a S-shaped curve, fits the long term trend of traffic growth for many highly motorized countries. This could be illustrated for example by data from the USA, covering a period of almost 70 years (Figure 4).

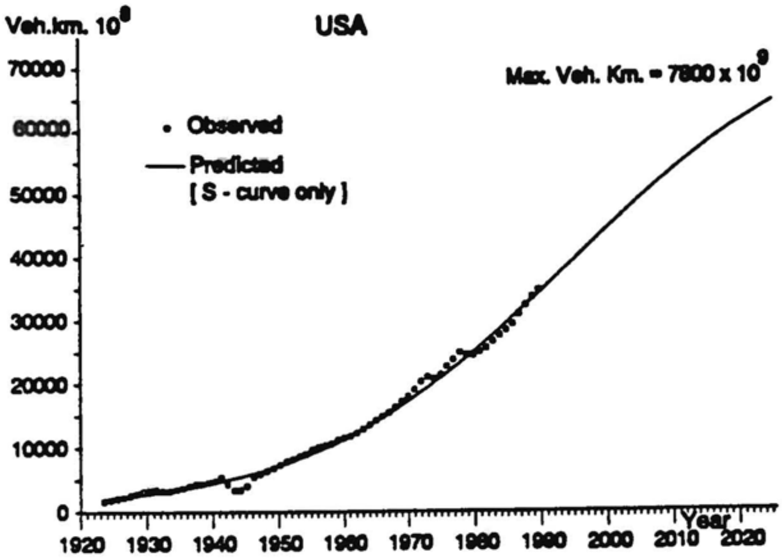


Figure 4. The S-shaped development of kilometrage in the USA.

Based on this curve a saturating level could be derived, assuming a growth of kilometrage could not be infinite. Of course, forecasts about car-ownership and growth of a population could be used as well to define a certain saturation level.

The growth of motorisation is accompanied by exponentially decreasing curve for fatality rates. This means a reduction in annual road fatalities per kilometre driven with a constant percentage (log-linear trend), although this percentage differs from one year to the next. The exponential curve is given for the USA, as an example (Figure 5).

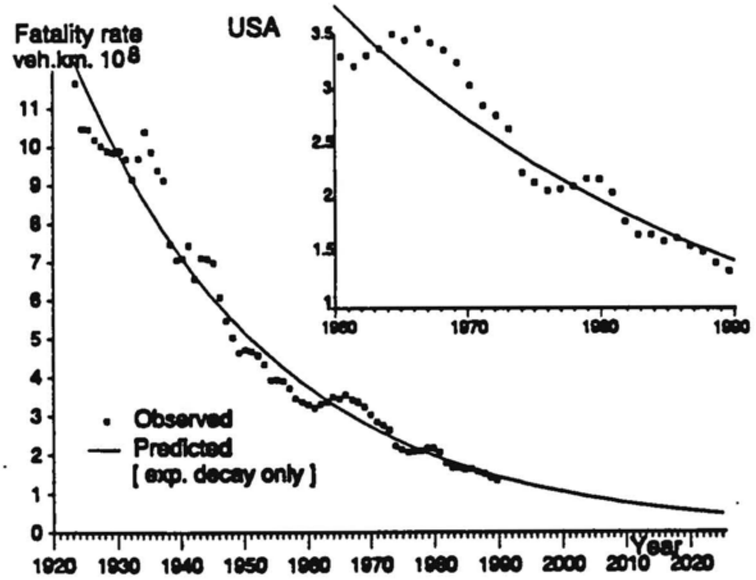


Figure 5. The exponential decay of the fatality rates in the USA.

The percent decline per year differs for different countries. Higher rates do not correspond with higher decline rates, although some indication could be found in different highly-motorized countries that nowadays the fatality rate decline is lower than in the past.
Koornstra and Oppe concluded on empirical data that cyclic modifications should be added to the long term macroscopic trend of mobility growth and of fatality rate decrease as well, although some space for discussion remains. **Just by combining both developments as a product [fatalities = fatalities/kilometrage * kilometrage] the development of fatalities could be described (Figure 6).** This lead to the conclusion that a reduction in number of fatalities ought to be the result of a higher decrease in fatality rate than increase in mobility growth. Should the growth in mobility accelerate, for example due to high economic growth, then extra attention should be devoted to (road safety) measures with the aim of further decreasing risk in road traffic.

Figure 6. Relation between mobility, fatality rates and fatalities.

The following interesting results of these modelling activities are of great importance for policy making in Central and Eastern European Countries. First of all, remarkable differences are to be notified between different countries: high reduction rates in Japan and Finland (ca. 10% per year) and lower rates in the UK and USA with ca. 4%. It seems to be that the more recent the motorization and the more explosive, the larger the annual decrease in fatality rate. **This indicates that reduction rates of 8-10% in fatality rates must be considered as realistic targets for Central and Eastern European countries.**

Secondly, a correlation has been established in highly-motorized countries between traffic growth and fatality rate reduction: the slower the growth of mobility the less the reduction in fatality rate. High traffic growth percentages correspond with high fatality rate reductions in highly-motorized countries. However, in no sense this correlation is a result of a natural law or a spontaneous development. We might consider this correlation as a collective influence to adapt a society to growing traffic. Growing traffic requires an enlarged, renewed, improved and well-maintained road traffic system. This traffic growth and its corresponding adaptation results in better and newer roads, increasing mean driver experience, newer and safer vehicles and appropriate traffic regulations and enforcement. All highly-motorized countries went through this adaptation to mass-motorization. And a lot of information is available nowadays about effective measures to improve road safety. **So, if (accelerated) traffic growth is not accompanied by appropriate risk reducing countermeasures and activities, a (disastrous) increase of road fatalities might be an outcome.**

But, thirdly, a lagged correlation between traffic growth and fatality rate reduction were observed. So, after some years high traffic growth lead to higher fatality rate reductions. This could be understood as time-lag which is needed to implement effective countermeasures for risk reduction. But this mean more fatalities due to traffic growth and some years later, hopefully, reduction. **The lesson to be learnt here is, when accelerated traffic growth is anticipated, no time has to be lost to invest in safety!**

The developments of road traffic and casualties in Poland might serve as an example to illustrate the developments in Central and Eastern European countries. Figure 7 clearly shows that the average decrease in fatality rate over the last ten years (1982-1992) has changed in an increase, which could be considered of a temporary nature.

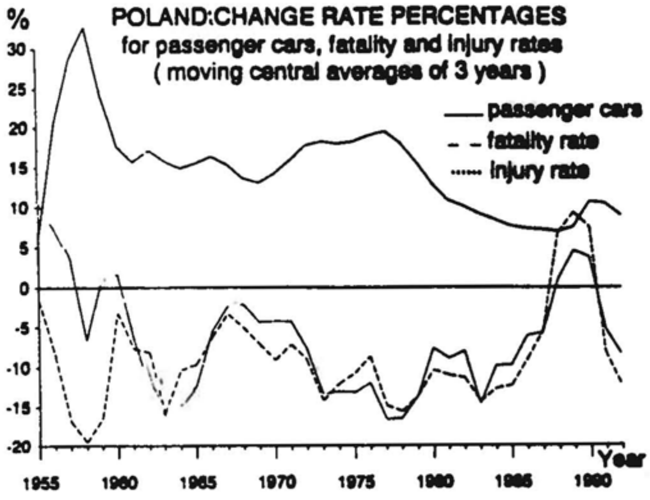


Figure 7. Rate change percentages in Poland.

The question is what to expect from the future? Two different scenarios could be made. In the first one we assume that the steep increase in fatality rates and fatalities form a part of the long term development in Poland (Figure 8A). Based on the assumption that the situation during the end of the eighties was from an extraordinary nature and says nothing about future developments Figure 8B could be composed.

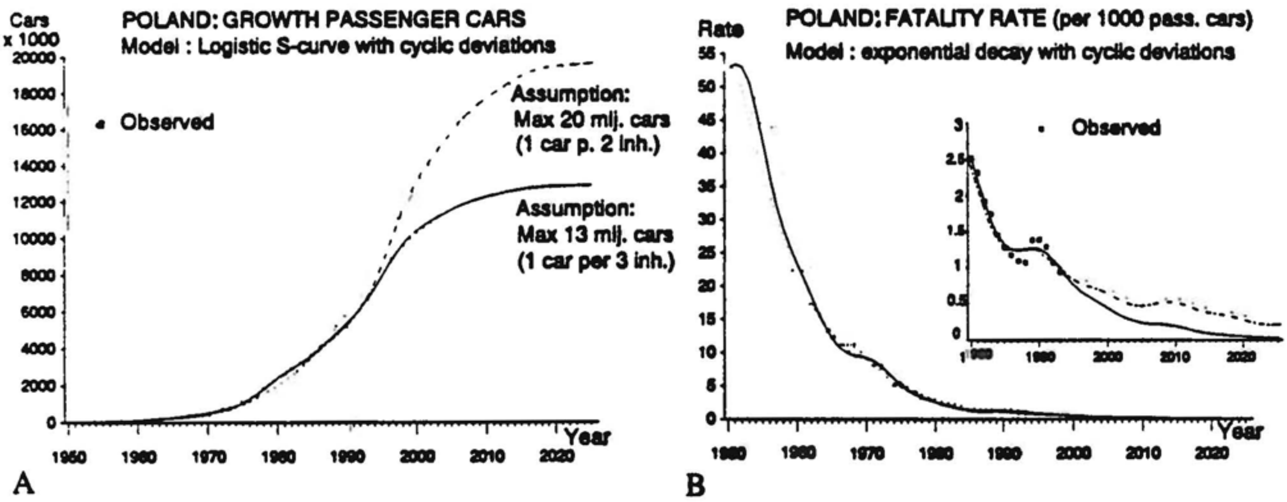


Figure 8. Predicted fatalities in Poland; A: data from 1953 to 1993 and B: data from 1953 to 1988.

From this the conclusion could be drawn that still a change exist of unfavourable developments in this field. But by investing in the quality of the transport system more favourable developments could be reached as well. Traffic growth, quality of the road transport system and road safety are strongly related. This ask for integration of road safety policy in traffic and infrastructure policy. **When traffic growth will be accompanied by appropriate risk reducing measures, also in the field of infrastructure, casualty rates could decrease and, accordingly, the number of casualties.** Without appropriate measures to reduce casualty rates the number of casualties will increase!

5. Road safety: a social and political problem

Road use fairly seldom results in an accident for a road user. On average a road user in the Netherlands gets involved in a fatal accident every 10 000 years. It is understandable that the risk of an accident occurring is virtually of no importance in the daily driving experience of a road user. Looked at in this way, road safety is not a problem.
However, because a great many people live in a country and use the roads and because there are a great many streets and junctions, a completely different picture emerges. Viewed collectively, there is indeed a problem. Every year tens of thousands of people die in road accidents in CEECs (compared to 50,000 per year in the EU), including many children and young people. In addition, hundreds of thousands of people are injured in road accidents, which makes heavy demands on the health service as many accident victims are permanently disabled. All this results in substantial economic losses (1 - 2% of the GNP).

In addition to the factual, objective consequences of accidents, road safety has another, more intangible and subjective dimension. Responsible citizens complain to the government about hazardous situations: people drive too fast or a crossing is dangerous. There are parents who are bothered by the feeling that something could happen to their children in traffic. These are objective and subjective aspects of the same problem, a problem that, individually, results in tragedies, a problem that incurs enormous social costs for society as a whole.

Yet road safety does not seem to be perceived as a major social problem; nor is it perceived as a major political problem. If a society does not appear to take road safety seriously, it is extremely difficult to gain public support for road safety measures, either from institutions or from individual citizens and road users. A form of social mobilisation is involved here, the first phases of which are problem identification and problem recognition. Public support based on public awareness is no static concept, but rather a dynamic one. Public support can be created and if it exists one day, it can diminish the next. The result is that 'maintenance' is needed. In addition to establishing an effective organisational structure, achieving public support is one of the first activities that could be carried out within the framework of an (intensified) road safety policy.

Influencing social norms of behaviour in traffic follows naturally from this (Evans, 1991). Hence in some countries, drunk-driving has been reduced not only as a result of more intensive police enforcement, but also because a successful policy has been pursued to reduce the social acceptability of drunk-driving. Such a campaign is even more effective when it fits in with a more general campaign to discourage people from drinking alcohol ('alcohol ruins more than you think' and 'enjoy, but drink in moderation'). It appears that these forms of behavioural influence are also effective in other areas (smoking, healthy diet, physical exercise) and can be in the field of road safety.

An approach known as social marketing has recently begun to play a part in road safety policy. It includes phases of analysing the 'market', determining the needs and requirements of the target group, formulating clear objectives, strategies and implementation programmes (OECD, 1993). There is an impression that if this approach had been adopted earlier, certain policy objectives would have been achieved earlier and at lower cost. This conclusion is partly due to the fact that the belief in legislation and subsequently in the enforcement of legislation has diminished. This option does not appear to lead to the objectives set or else would involve prohibitive costs.

This does not mean to say though that no legislation would be required for some issues. There is sufficient evidence (Wegman, 1992) that legislation and the associated enforcement of legislation has positive effects on behaviour (speed limits, wearing a seat belt etc.). What is in fact meant here is that legislation should not be the start of a journey that leads to a change in behaviour, but rather it should be the end of the journey. Legislation would only be introduced when (a considerable proportion of) road users have seen the sense of changing their behaviour and have demonstrated the desired behaviour to a certain extent. This approach will probably result in less discussion about the content of legislation and in better legislation!

Now that there are signs of regained freedom in CEECs, manifested by an unwillingness to obey traffic regulations etc., it might be interesting not just to react by introducing new and stricter legislation in this area, but to follow this social marketing approach.

6. Road safety: a policy problem

For years countries have had the task of improving road safety and many, if not all countries in the world will make an effort in some way. Politicians and policy-makers in positions of responsibility call road safety a serious social problem yet it does not seem to be taken seriously as a policy problem. The following statements have all been made at some point:

- The yardstick used is inadequate. Accident records are incomplete and those accidents that are recorded occur throughout the entire road system, seemingly unsystematically; there is nothing that can be done about it.
- Road safety measures encounter opposition, especially those that restrict individual freedom.
- The effects of measures are debatable and unknown in advance. With regard to the cause of and remedy for accidents, different opinions are fairly often expressed and it cannot be proved whether these are right or wrong.
- The effects of measures are not subsequently 'measurable'. It often proves difficult to make statistically sound judgements because the effect of measures is often difficult to 'isolate' from other influences and because chance fluctuations can play a major part.
- Central government cannot do everything alone. Tackling the issue of road safety requires effort from many bodies. This means that good collaboration is essential. It is difficult to achieve good collaboration and a lack of it can be demotivating.
- There are doubts about what authorities can do. It is difficult to determine the effects of measures taken by authorities in terms of a reduction in accidents and at first sight the effects are not apparent. As a result of this the view can - mistakenly - take root that a local government policy makes no difference.
- Understanding of road safety problems is not enough, whereby common sense and personal experience as a road user sometimes determine the view of individual

policy-makers and politicians. This situation in itself leads to disputes as regards content and policy.
- There is a lack of administrative precedent and experience in implementing measures. Tackling the issue of road safety - particularly where road safety is a facet of other areas of policy - has virtually no administrative precedent.

More than enough reasons for coming to the conclusion that formulating and implementing a road safety policy is no easy task. Quite apart from the 'usual' problems such as inadequate funds and a lack of sufficiently qualified personnel, whose numbers are, moreover, dropping, due to government cuts. In policy and administrative terms the improvement of road safety is a persistent and tricky problem requiring a great deal of inventiveness and decisiveness and involving a real risk of failure. To put it briefly, the improvement of road safety is not a subject for timid administrators who like to play it safe. To cope with these problems a recent OECD-study 'Targeted road safety programmes' (OECD, 1994) could be helpful.

7. A National Road Safety Plan

A National Road Safety Plan is an important means of getting and keeping this subject on the political agenda. What is more, a plan of this kind can also act as a reference for implementing policy. First and foremost, the plan should include a philosophy about how road safety is to be improved, in the short term and in the longer term. The plan should therefore open up possibilities and indicate frameworks.

A plan is not enough in itself. Conditions must be established that the plan will also be implemented. In the OECD-study 'Targeted road safety programmes' the conclusion is drawn that, based on findings available, "targeted road safety programmes do not guarantee better results than routine-type safety activities or automatically improve either programme planning or the likelihood of the desired accident reduction. However, a number of the features of targeted road safety programmes encourage good practice in programme planning. Clearly formulated road safety targets can guide policy making in a better way than less elaborate or less detailed road safety targets and, thus, improve safety performance."

In the Netherlands, a great many policy plans have emerged in the past in the area of road safety. Based on this experience, it is advisable to devote some attention to the following 'ten commandments' in a road safety plan:
- raise awareness and support in society and create public acceptance of safety measures;
- integrate with other areas of policy;
- create network of well-educated professionals and interested citizens;
- use know-how when implementing policy;
- check quality of implementation;
- combine long-term strategy with short-term successes;
- start with well-known and simple cost-effective measures;
- reduce chance of human error by increasing predictability in traffic, making traffic more homogeneous, reducing speed and separating road user categories;
- improve vehicle safety;
- improve emergency services and hospital care.

An international team of experts developed a methodology to assess the effectiveness of a

'National Road Safety System' (Worldbank/European Community, 1992). Two functions are defined in this methodology:

I. In the framework of the **general design** of road safety policy
    1.1. Set up a road safety policy
    1.2. Identify the problems
    1.3. Identify and maintain specific skills
    1.4. Obtain the necessary financial resources

II. In the framework of the **implementation** of the road safety policy
    2.1. Set up general regulations relating to behaviour and protection of drivers (and passengers).
    2.2. Improve safety level of infrastructure
    2.3. Train and educate
    2.4. Control and penalize
    2.5. Ensure good conditions of new vehicles and those in use
    2.6. Inform and make aware
    2.7. Set up an effective emergency service for accident victims
    2.8. Evaluate before and after the efficiency of measures and programs

8. Organisation of a road safety policy

A former Dutch Minister, who was responsible for coordinating the road safety policy, once wrote: "As Minister of Transport, Public Works and Water Management, I am responsible for the national road safety policy. I do not shirk this responsibility. However, I would stress once more that a Minister alone can accomplish very little. Road safety is a matter that directly concerns half of the Cabinet, but also, and particularly, administrators of provinces and local authorities, not to mention over 14 million other Dutch people" (Ministry of Transport, Public Works and Water Management, 1991). The following conclusions were drawn from this:

- attach more importance to coordination within the Cabinet;
- more targeted collaboration by all of the organisations within a province that have a role to play within the context of road safety;
- persuade citizens to obey traffic regulations that are vitally important.

Attaching more importance to coordination within the Cabinet means first and foremost making a statement of political will. A statement of this kind, supported by the Cabinet, legitimises activities relating to harmonising policy in various areas in the context of the improvement of road safety. The 'competitive position' of road safety is reinforced by the quantitative terms of reference which have been in existence for some years now: 25% fewer casualties by the year 2000 and before 2010 50% fewer deaths and 40% fewer injuries than in 1985 (Ministry of Transport, Public Works and Water Management, 1991).

Over the years it has proved necessary to have a separate unit within central government where road safety policy is coordinated and specific aspects of the policy can be implemented. Due to the complexity of road safety problems, some countries have opted to house this 'Road Safety Agency' within the offices of the Prime Minister (Japan, France). Other countries have brought an unit of this kind within a specialised department, usually the department that is responsible for transport and/or infrastructure. This agency organises (formal) discussions with other ministries. In addition, discussions with other organisations and institutions, that are of relevance to road safety, are very important.

If, in addition to coordination, an unit of this kind is also allocated executive tasks, two risks should be combatted. First of all that other departments within central government (in the field of physical planning for instance, the health care system or the police supervisory organisation etc.) think that, because a road safety unit exists, they can be less involved. It might also happen that the dynamism of the road safety unit takes the initiative away from other bodies.

To summarise, an attractive type of organisation is a separate unit or agency which combines implementation of policy (particularly within the road safety sector, such as driving lessons, road safety campaigns) and coordination of policy (road safety seen as a facet of other areas of policy). This unit should have sufficient direct access to a Minister in order to be able to aim at an effective policy. The unit has a relatively modest budget to enable policy to be implemented by others based on the idea of 'setting a sprat to catch a mackerel'. In addition to carrying out its own tasks efficiently, the service will lay great emphasis on coordination by facilitating the activities of others, by providing encouragement and by making it attractive for others to contribute to promoting road safety.

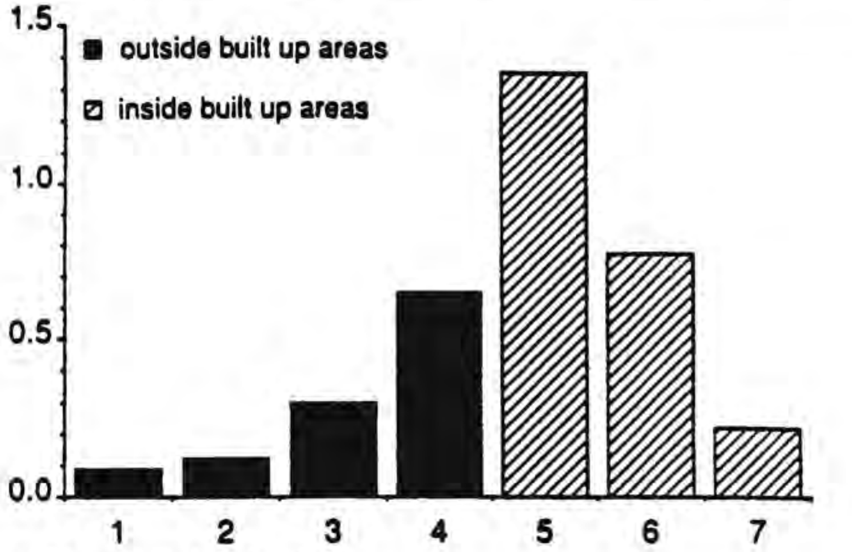
Neither one Minister alone nor central government alone will be capable of pursuing an effective road safety policy. In 1993, there are doubts about a 'makable society', but the view that central government could make a society finds little support any more. Other sections of government and private organisations are vital links. Local and provincial government in every country in the world has a crucial role to play in physical planning and in the construction and maintenance of road infrastructure, where they enjoy a relatively large degree of policy freedom. The more active these administrative layers are, the more knowledge that is available, the higher the budget allocated to improve road safety, the more effective the efforts made in terms of a reduction in the number of road accident casualties. Perhaps this is one of the most important organisational provisos for a successful road safety policy.

Another effective means appears to be to allow private organisations to participate in formulating policy and to involve them in implementing aspects of the policy. What is more, private organisations need to work together and reinforce one another rather than hinder one another. The road safety unit has an important part to play in this process. Private organisations and organised interest groups that are working together must be considered capable of exerting social pressure and creating public support within society. A road safety parliament or a road safety council might be seen as a formal expression of these views.

9. Infrastructure policy and road safety

Since the beginning of the fifties a great many measures have been taken that have resulted in a substantial reduction in the risk of having an accident and have also led to a decline in the annual number of casualties. It seems that it is not possible to give a satisfactory explanation for the actual development; it is, however, possible to give an expert opinion on the basis of research findings.

The sixties and seventies saw a great deal of investment to expand and improve road infrastructure in highly motorized countries. This resulted in a considerable expansion of the motorway network and in through traffic being diverted away from built-up areas. Comparison of the fatality rates for various types of roads reveals that the traditional roads (main roads within built-up areas and dual carriageways outside built-up areas, to which all traffic is admitted) are among the most hazardous (Figure 9). The fact that the proportion of safe types of road (calming areas and especially motorways) in the total length of infrastructure has increased, and that the proportion of mobility on these roads and streets has increased even more sharply, has certainly contributed to the drop in the fatality rate.



1. Motorway: 100-120 km/h
2. Motorroad: 100 km/h
3. Arterial rural road: 80 km/h
4. Local rural road: 80 km/h

The most elementary classification for the built up area is subdivided into:
5. Arterial roads with a speed limit of 50 km/h (sometimes 70 km/h)
6. Residential streets with a speed limit of 50 km/h
7. "Woonerf" and residential street (approx. 8 km/h to 30 km/h)

Figure 9. Injury accidents in the Netherlands (1986) per million vehicle kilometres.

A large part of the present road system, however, is still that roads and streets are expected to fulfil several incompatible functions at the same time, where the road user has generally to guess what to expect from the road traffic situation and is presumed to guess what others expect from him, where road users can and do drive at relatively high speeds, where large differences in speed are possible and do in fact occur, and where encounters with other road users coming from different directions are possible (SWOV, 1993). These factors explain the relatively high risks on these roads. There is some talk of a road system that has all the characteristics of gradual adaptations (not geared to one another) of the increase in mobility. There are three principles which, if they were adopted systematically and consistently, would result in a substantial decrease in the number of casualties. These three safety principles are functional use (preventing unintended use of the infrastructure, related to the function of the road), homogeneous use (preventing large discrepancies in speed, direction and mass at moderate and high speeds) and predictable use (preventing road users from experiencing uncertainty).

If these principles were to be adopted, three functions of the road system would be clearly discernible for the road user: the flow function (rapidly processing with through traffic), the access function (making residential areas and districts easy and rapid accessible) and the property and residential function (making homes and shops accessible and at the same time making the street a safe meeting place). The design of the roads should be adapted to the allotted function; combinations of functions should be excluded as far as possible. It would have been advisable when constructing and expanding the road system to adopt the principles mentioned as far as possible, which would have meant that such large investments were not necessary (in retrospect). For that, a reference plan for the whole infrastructure would have been needed in which a hierarchically designed road system should have been the starting point. Furthermore, there would have to have been design guidelines in which road safety formed an important starting point and where (legal?) steps were taken to prevent deviation from the required design quality.

Now that CEECs can expect an increase in mobility and expansion of the infrastructure, it would be advisable to speak out in favour of such an approach instead of acquiring a higher degree of road safety at a later date at a much higher cost, as is the case in highly motorised countries at present.

This does not mean though that no further gain in road safety could be achieved in the short term with infrastructure measures. On the contrary, it is advisable to take low-cost measures in places where many accidents occur. Furthermore, highly motorised countries have amassed a great deal of knowledge, which at present is termed basic but which has been built up over many years, about the effect of road design, road construction and materials on road safety. Examples include the use of marking and signposting, road surfaces (unevenness) and winter maintenance. From the point of view of harmonisation it is also advisable for CEECs to adopt the general course of action of becoming a party to international treaties and conventions in this field.

10. Conclusions and recommendations

1. If it is assumed that the recent political and economic changes in Central and East European Countries (CEECs) result in economic growth, there will be an extra increase in mobility which, unless road safety measures are taken quickly, will lead to a decrease in road safety in CEECs. The increase in the number of road accident casualties in recent years proves that this expectation is correct. The number of casualties per 100,000 inhabitants and per 10,000 vehicles is (substantially) higher in CEECs than in highly motorised countries.

2. It is realistic to expect that an effective road safety policy in CEECs will result in a smaller decrease in road safety, as was the case in highly motorised countries until the beginning of the seventies.

3. With the knowledge that is presently available about the developments in road safety and the effectiveness of measures in highly motorised countries, the approach adopted in these countries could perhaps have been different than was the case in the past. CEECs might consider learning from this.

4. Road accidents usually occur as a result of a critical combination of circumstances and seldom have just one cause. There appear to be many opportunities for preventing human error that brings about road accidents (cf. the so-called phase model of the accident process). This could be used as a starting point when formulating a road safety policy. This means that thoughts and arguments with regard to road safety have to play a role in decisions concerning physical planning and urban development, in traffic planning, in policy concerning education, the police and justice system, the health service etc. This calls for integrated road safety programmes and requires the government to be organised in such a way as to reflect these. A unit with the important task of coordinating policy is a vital aspect of this organisation.

5. A politically sanctioned National Road Safety Plan, that is based on the starting points formulated above, is regarded by the entire road safety community as being its 'ownership', can count on the support of (large sections of) the public, is based on a clear analysis of road safety and contains concrete (quantitative) targets, can make a significant contribution to improving road safety. The implementation of this Plan should be monitored and the evaluation results of the monitoring should, if necessary, and in view of the targets to be achieved, lead to additional efforts being made.

6. The improvement of road safety should be situated in the long-term perspective of development towards 'sustainable' safe road traffic. Such a long-term perspective (20 years or more) should include concrete short-term goals. Steps should be taken to prevent measures being taken that jeopardise long-term targets: making compromises hinders the achievement of long-term targets and leads to extra costs being incurred.

7. Based on political will, on a proper organisation and making use of existing knowledge on the most effective and efficient measures, road safety can be improved. The chain is as strong as the weakest link. Improvement of road safety is an organisational and management problem in which the role of the government is crucial. Financial resources - or rather the lack of them - should not so much determine targets, but rather should only affect the speed at which the objectives can be achieved.

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Road design and design standards

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Two thousand years ago, roads as we know them nowadays did hardly exist: the connections between towns and villages were no more than tracks which had gradually come into being through the landscape as people needed them to be able to travel. Personal needs to travel were not so manyfold in those days; the main goal would have been the transport of goods.

The first roads that were actually built on our continent were created by the Romans. No much attention was paid to traffic safety by that time. We must assume that most of the hazard on the long lonely stretches of road between settlements was created by robbers rather than by imperfections of the roads themselves or by the presence of other road users.

Things have changed since. Road hazard has become a major factor threatening our lives and health. On the average, everyone of us will get injured in a road accident during his lifetime.

Many studies have been carried out on the causes of road accidents. Mostly, a distinction is made between causes that have to do with human failures, with vehicle failures and with road failures.

Those studies are being made by using data on accidents that have really occurred. In some cases, there are differences in attributing the causes of accidents to one of these three categories, but the major part of the accidents is usually blamed on human failures.

Of course, there is an essential difference between vehicles and roads on one hand and man on the other hand. Vehicles and roads are dead things that are as they are, with only a very little chance of an unexpected break down. A human being, on the contrary, has the possibility to act in an endless number of different ways. This may be considered as an advantage, because he can choose the proper traffic behaviour under different conditions. He can even react to unexpected events to a certain degree. He can discover irregularities in the functioning of his vehicle, see a hole in the road, or perceive erroneous behaviour of his fellow road users; and he can adapt his traffic behaviour accordingly.

There is a reverse of this medal, however. A human is no machine: he makes many more mistakes, especially in modern traffic where he must constantly make decisions and act accordingly. The large number of variations in possible actions is adversely affecting his performance. This is why he is blamed in most cases.

In view of this, everything must be done to relieve the task of the road user. The easier his driving task, the less errors he will make. Less human errors will result in less accidents.

Proper road design, geared to the limitations and abilities of the drivers, is crucial to prevent human errors in traffic as much as possible. To this end, three safety principles were developed to be applied in a systematic and consistent manner:

- preventing unintended use of each road;
- preventing large differences in vehicle speed, mass and direction of movement, thus reducing in advance the liability of serious conflicts;
- preventing uncertainty amongst road users, by enhancing the predictability of the road's course and of the behaviour of fellow road users.

How can we design roads in such a way that these principles are met?

Unfortunately, the relationships between separate road features and road safety are not yet well understood quantitatively. The finding of such relationships is obscured by a variety of disturbing factors, such as the variety in road users, in vehicles, risk increasing circumstances, different traffic regulations etc. So there is still uncertainty among traffic engineers whenever they must design a road.

In this respect, design *standards* can be of great help. If design standards are available, they may provide the answer to many questions arising in the mind of road designers. However, some important problems exist in this field.

First of all, not all European countries possess design standards for all road types. And if they do, they do not always apply these standards, owing for instance to lack of sufficient physical space or because the standards may lead to expensive designs. When standards are applied, some space of interpretation may lead to different road design even in the same jurisdiction. Furtheron, there is no accordance between various countries on the matter of standards.

Due to the lack of hard evidence of the relationships between road design and safety, those responsible for compiling design standards tend to rely heavily on their own judgements. Most of the time they are inclined to use a limited amount of well-known and often cited references. Application in some Western European countries of the U.S. Highway Capacity Manual in the fifties and sixties is a famous example in this respect, and probably the best which could be done under circumstances of lacking appropriate European research results.

The partial unavailability and the non-accordance of design standards for the road network in Europe increase risks and therefore contribute to the actual size of the road safety problem.

Activities focused on full availability of road design standards and on their mutual accordance are expected to fulfil better the three road safety principles that I mentioned earlier, and, consequently, are expected to lead to a safer road network.

So far my introduction to a study that was made on this matter by the Dutch SWOV Institute for Road Safety Research. SWOV has studied the question whether proper road design, based on well-established design standards, could reduce the enormous number of fatalities and injuries on European roads each year. The work was commissioned by the European Commission, and we have carried it out in close cooperation with experts from most of the 12 member states.

The aim of the project was:
- to analyse to which degree road safety arguments have been a factor in compiling existing road design standards in the European countries;
- to find ways how to increase the impact of the safety aspect in future design standards.

Within the framework of this project, a number of questions were treated:
- Why do we build roads? What are their functions?
- How do we build roads? Which criteria do we use in designing them?
- What is the benefit of using design standards?
- Should all standards be equally firm?
- Which are the consequences of international harmonization?
- How to treat departures from the standards?

Definite answers to all questions were not provided, but I will give you some impression of the possible ways of finding the solutions.

The first safety principle: preventing unintended use of each road, calls for first establishing the intention of every road. In other words, the first question was: *Why do we build roads? What are their functions?*

Roads are built with one major function in mind: to enable people and goods to travel from one place to another. We call this the *traffic function*. Differentiating within this traffic function, a distinction can be made between the following aspects:

- the *through* function: enabling rapid processing of long distance traffic;
- the *distributor* function: serving districts and regions containing scattered destinations; and
- the *access* function: granting direct access to properties.

In built-up areas, an other important function of a road may yet be distinguished: allowing people to stay in the vicinity of their homes, for social contacts or outdoor activities. This function has received increasing attention of road designers during the last decades, especially in residential areas. We call it the *residential function.*

The distinction between the functioning of roads described here is often not so clear. In the present situation, most roads are *multifunctional*, i.e. they perform a mixture of the aspects of the traffic function in varying combinations. This is when problems arise because the three aspects of the traffic function lead to contradictory design requirements. For instance, long distance traffic is associated with high speeds, while access to properties is identified with low speeds.

The contradiction between the requirements for satisfying both the residential function and aspects of the traffic function is even greater. Only the direct access function of a road could to a certain extent be satisfactorily combined with the residential function.

As an aid to solve the contradictions between all the functional requirements and to nevertheless enable the roads to fulfil their various roles like they should, road *classification* is generally introduced. The main purpose of road classification should be that the actual function combination of a road is made more clear to the road users by means of distinct features, thus relieving the task of the road users.

Road functions and classification are dealt with extensively in a separate presentation during this workshop.

The next question was: *How do we build roads? Which criteria do we use in designing them?*

Roads are designed with a large number of criteria in mind, such as:
- travel time
- comfort and convenience

- safety
- environment
- energy consumption
- costs
- town and country planning.

They all affect the final design of a road.

Most of the criteria are of mutual influence; some combinations of criteria are conflicting. The art of designing a road is predominantly the art of giving the right weights to the various criteria, in order to find the most satisfying solution.

It is important to recognize that safety has usually no particular position and must compete with the other criteria.

Not all criteria are dealt with in the same way. Some of them, p.e. comfort, are dealt with qualitatively, whereas for others, such as noise pollution, we adopt quantitative norms. Some are considered explicitly in the course of the design process, others are allowed for implicitly, in one or more stages of the process. A third possibility is that criteria are dealt with on a separate level through the setting of specific norms.

Under these conditions, assigning the right weight to every criterion is not so simple; especially when the importance of criteria is subject to political influence, the final outcome is unpredictable.

Safety is usually among the criteria that are allowed for *implicitly* and only *qualitatively*: at every step in the process, the designer is supposed to take decisions with safety *in mind*, but decisions are rarely taken exclusively for the sake of safety. Thus, at the end of the process, it is difficult to judge to which extent safety has been taken into account.

It is clear from this that there are limitations to the levels of safety which are, and can be, achieved through the traditional road design process. It is perhaps about time to move towards a more explicit formulation of safety levels. The existing knowledge of safety levels associated with various forms of transport and on various road types should lead us to formulate required safety levels to which the total road network system should be designed. It should be noted that we run some 100 to 200 times greater risk per passenger kilometre in road traffic compared to rail and aviation traffic.

A first step could be put by requiring safety audits, not unlike the environmental impact assessment procedures in a number of countries.

Only recently, another interesting attempt in this respect has started in The Netherlands, by developing the concept of *sustainable safety*, i.e. the creation of a road transport infrastructure that can provide an *acceptable* level of safety in the long run. I will return to this point in my presentation on road classification to-morrow morning.

This brings us to the third question: *What is the benefit of using design standards?*

Geometric design standards are generally supported on three main grounds:
- to ensure *uniformity* among different designs, thus making traffic situations and road user behaviour more predictable;
- to enable the *existing expertise* in geometric design, to be more broadly applied; and
- to ensure that road *funds are not mis-spent* through inappropriate design.

To serve these aims standards must have a certain degree of coercion. Coercion may be felt as a support when designing a road, as I said earlier. In this respect, standards can be a great help. But compelling standards have also disadvantages. They diminish the freedom for the designer to find the right balance between the various criteria. Important decisions have already been taken for him; he can no more weigh up carefully the various interests.

But even if there is space for a choice, sufficient information on the 'amount of safety' incorporated in each of the possible standard solutions is lacking in most cases. Whereas safety ought to have been a major consideration underlying the design standards, its actual impact is doubtful.

And, finally, innovative developments are almost impossible if compelling standards have been set.

It appears from this discussion that the *status* of a standard is a matter of interest, i.e. is the standard compulsory; is it just a guideline; etc. This status should, of course, be closely related to the technical soundness of the standard. Making a standard compulsory is only justified if there is the certainty that the solution offered is the optimal one.

Possible improvements in this situation might be achieved by:
- assuring a better connection between research results and standards; and by

- differentiating the status of the standards.

This brings us to the question: *Should all standards be equally firm?*

An attempt to classify standards with regard to their firmness was made in the Dutch standards for urban roads. The facilities described are distinguished by means of a stars system as follows:

*****	*regulations* to be complied with;
****	*guidelines* from which can be deviated only with a sound motivation;
***	*recommendations* to be preferably followed because it is assumed that their effect is favourable;
**	*suggestions* of which a favourable effect is expected;
*	*possibilities* of which a favourable effect is suspected only.

To classify an individual standard, an analysis was made of the reasoning behind it and the nature of the assumptions made. In doing this, our suspicions were confirmed that traffic safety had not been the only criterion when the standards were drawn up.

There is a need for a better understanding of the degree of technical firmness of respective standards, with special regard to the safety aspect. This information, reflected in the status of each standard, will enable the designer to make use of the standards in the most appropriate way. Then, also, it will become clear that some standards give the impression of being firm, while they were actually built on assumptions.

We arrive then to the question: *Which are the consequences of international harmonization?*

Harmonization of road geometric standards within Europe has the same advantages and disadvantages as apply to the setting of national standards, but now on a larger, international scale. However, there are some additional problems.

At present, design standards vary greatly from country to country, partly because safety is implicitly treated in a different manner in the various design procedures. This is an alarming conclusion, especially in view of the expected continuing growth in tourism and trade.

Several attempts were made in the past to harmonize elements of different standards, with more or less success. Harmonization can be strongly promoted by producing sound results of research rather than by negotiating.

Harmonization of design standards will tend to incline towards the higher norms accepted in some countries, thereby augmenting levels of safety. In this lies also one of the drawbacks of harmonization, because a higher norm is most likely associated with higher costs. There will be different willingness to accept high standards because of varying economic situations.

A third drawback might be the radical change in standards that could be necessary in some countries. Harmonization is especially hindered in the case of different driving behaviour and cultures in the countries involved.

National standards contain sometimes specified margins around certain values, which may be used by the designer 'in emergency'. Unfortunately, it is not always indicated what situations can be described as emergencies.

Thus, as international harmonization is concerned, the last question of my list will repeatedly be raised: *How to treat departures from the standards?*

Must departures be tolerated, and under what conditions? Ought margins to be set within which national standards are allowed to diverge up- and downwards? What will be the implications, especially in terms of safety and costs, when allowing lower standards?

I will deal only briefly with these problems. A possible solution could be a sound system of margins allowing designers to depart from certain values, accompanied by a set of well-founded instructions indicating under what conditions departures are tolerated. Rules to allow systematically for the use of margins are in force in some countries only.

Let me finish by summarizing the main findings of the study.

We must conclude that the safety aspect is not clearly represented in existing design standards. To improve the impact of the safety aspect among the other criteria we arrived at the following recommendations:

- a more explicit treatment of safety is wanted
- a better connection between research results and standards is required
- there should be a differentiation in the status of the standards, and
- a system of margins, together with a set of instructions how to make use of it, is worth considering.

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Road classification

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Need for clear traffic situations

Most people do not travel for the sake of travelling itself, but because they want to go elsewhere or because they want to bring goods to a place somewhere else. Or, better, want to **be** elsewhere, or want the goods to **be** elsewhere. For most people, therefore, travel time is lost time. That is why they try to minimize the journey times, and the most natural way to do this is by travelling as fast as reasonably possible.

This means that they do not have ample time to study road situations, but that they are forced to take a view of these situations at a glance, and take the necessary actions within a short time. Therefore, road situations must offer clear information to all road users about the route and manoeuvre choices they can make to find their way.

Road characteristics tend to be also associated with traffic characteristics; they elicit certain expectations based on earlier experiences. For example, motorists driving on roads with dual carriageways, wide lanes and a straight course will generally anticipate high speeds and not take into account slow traffic nor intersecting traffic. So, if unexpected traffic characteristics occur on such a road (e.g. the presence of an agricultural vehicle) or a sudden change in road characteristics (e.g. a sharp bend), then this demands extra effort from the road user. His task becomes more difficult instead of easier. And our objective should be to relieve the task of the road user.

The road situation offers very important information to the road users on how to behave and to act. Road users 'translate' road characteristics into behaviour on the road. This should be the basis for a safe design of the infrastructure. The planners and designers of road networks, roads and junctions could still take more account of the behaviour - and the opinions - of road users.

It would be easy if all roads and all junctions could be designed and built identical. In that case, the expectations would be always the same, and traffic behaviour likewise. But, roads are not built to please the road users, but to perform certain functions in the interest of the society. These functions, often more than one, may diverge largely from one road to another. Because of this, there are great variations in the design of roads and in the way they are being used. Another diversifying factor is of course that the environmental conditions may vary largely.

So we have the problem that, on one hand, there is a call for uniformity, and on the other hand, there is the need to diversify.

In this situation, road classification can be an important help. The main purpose of road classification from a safety point of view is that the functions of a road are being made clear, so that road users have a better expectation of the traffic processes on that road, and behave accordingly. To this end, the shape of a road must be consistently related to its functions.

The triangle purpose - shape - use

The intended functions - the 'purpose' - of a road should first be clearly expressed as part of the traffic policy plan. It is then the task of the road designer to give 'shape' to those functional requirements. In addition to the road infrastructure, there are also traffic rules which must finally yield a proper 'use' of traffic facilities. The relationship between 'purpose' (= intended functions), 'shape' (= design) and 'use' (= actual functions) of a road may be shown in a triangle.

Starting at the top, the 'purpose' (intended functions) is understood to mean the tasks which should be fulfilled by the infrastructure element. This intended functioning is generally drawn up in a traffic plan, after town planners, technical experts and politicians have expressed their views. The registered transport needs may or may not be accepted and proposals can be made for the improvement and expansion of traffic links.

Next, the 'shape' as realized on the basis of the design translates the functional requirements for traffic facilities into road constructions.

'Use' is understood to mean the traffic behaviour as manifested on the realized road network. These actual functions of the traffic facilities can then be compared with the intended functions. The difference between objective and reality can be measured through the signals received about traffic obstructions, accidents, noise pollution and other forms of traffic related problems.

Using a road classification, we can steer many aspects of traffic behaviour in a desirable direction. Such a structural approach will exert a positive influence on the quality of the traffic process in terms of flow, safety, comfort, environment and costs with the use of the road network. This means that road users should also have an understanding, conscious or otherwise, of the functional relationship between parts of the road network. In other words: the functions of the road and its environment, respectively, will have to be communicated in one way or another to the road users and also to persons residing along that road, since behaviour after all is the manifestation of actual functions.

Since several decades, a distinction within the road infrastructure is more and more being made between residential areas and 'traffic areas'. People live, work and spend their leisure time in the residential (and working) areas, while traffic areas are intended for the transport of people and goods, generally by means of vehicles. The traffic area consists of road networks which offer a great diversity in transport possibilities to suit the various types of vehicles.

It is mainly the speed options which imply a major consequence for road hazard on these road networks and for the quality of life in the adjoining residential areas. Roads are indeed intended for driving over, but not all roads are constructed to allow fast driving. In most existing situations, there is still no clear distinction between residential and traffic areas. People may live along roads, and vehicles are allowed to enter residential areas. Nevertheless, the traffic function and the residential function of a road are contradictory.

As the various possible functions of a road are a very important issue in this explanation, there is a need for a more exact description of what is meant in the respective cases.

Road functions

Within the *traffic function*, three aspects can be distinguished:
- the through function
- the distributor function
- the access function.

The *through* function of a road is primarily determined by the qualitative possibilities traffic should be offered to allow it to flow. The quality of flow increases with greater continuity and higher speeds. At a higher traffic volume, the same quality of flow can be offered by widening the road. This means that the allocation of the through function in principle is independent of traffic volume. Continuity and a relatively high flow speed are made possible through a continuous flow (without traffic turning off, crossing or entering).

In general, the desired quality requirements for the through function will be set at a higher level as the volume of through traffic increases. A distinction between through traffic and local traffic on a stretch of road is easy to make, in theory: through traffic does not have its origin nor its destination along that stretch of road or in the relevant district.

The physical road characteristics which accentuate the presence of a through function are recognized by the cross-section (for example broad, dual carriageways) and by the longitudinal profile (for example, due to the lack of tight horizontal and vertical curves). The more dynamic characteristics of the through function are determined by the traffic itself: for example, high and homogeneous speeds by motor vehicles only, driving in one direction without being hindered by intersecting traffic.

The *distributor* function (at the same time the collector function) of a road is determined by the need to enter or leave the road at junctions. The quantity of this 'distribution' increases as the number of junctions rises. In addition, the distributor function increases when there are more turning and crossing vehicles at the junctions. The distributor function will perform better if the vehicles on the road move at a lower speed, at least at the junctions.

The road characteristics which indicate the distributor function can be found at all junctions along the road. The frequency of such discontinuities is important. In addition, dynamic characteristics also determine the distributor function, for example markedly varying speeds over the length of the road as a result of a relatively large number of vehicles intersecting, turning off or entering. The design of the junctions should be derived from the intended combination of functions of the road.

The *access* function of a road can be derived from the function of the areas along that road. The static characteristics of the access function are determined by the constructions adjoining the road. These may vary due to the many possibilities offered by human activity. Recognizing the nature of these activities, despite the many variables, should not be a problem for the road user. However, the intensity of the activities is often wrongly assessed.

Destinations, and also origins, may be found along the full length of the road. Stopping and starting vehicles, entries to properties, etc. are a continuous source of possible irregularities in the traffic process. Low speeds over the full length are wanted.

Finally, in urban areas, roads and streets tend to have a more or less dominant *residential function* in addition to a traffic function. On these roads and in these streets, activities take place which have nothing to do with the transport of people or goods, but are the result of the presence of houses in the immediate environment (shopping, walking the dog, washing the car, children playing, parked cars, etc.).

An important section of the public road, specifically the pavement (footpath), serves to harbour people. But, people can also be found on the carriageway, for example to reach the other side of the road or to alight from a parked vehicle. In traffic, it is mainly the pedestrians - who are seen on the pavement and on the carriageway - who, sometimes too late, make the residential function of a road recognizable.

In practice, the traffic functions can be associated with driving traffic, and the residential function with the presence of pedestrians. Traffic function and residential function do not match very well. Only when the traffic function is of very low importance it can be combined with a residential function. This is the basic notion underlying the 'woonerf' concept and the pedestrian shopping zone. In all other cases, it is common to offer both functions their own area, in principle: carriageways and cycle paths for the traffic function, and pavements (footways) for the residential function.

Present situation with regard to road classification

Since the road users must be seen as the main 'consumers' of a road classification, the classification system should be fully targeted on them. But, the clarity of road classes for this target group is seldom considered in existing road classification systems. The classification is mostly intended primarily to assist the road designer.

Despite many discussions held amongst traffic experts, a universally accepted road classification has not yet been achieved. Each country has named and designed its roads according to individual insight. Road classification systems in European countries show also a mixture of objectives. Classification is often used by road administrators as an aid to distinguish between roads for totally other reasons than for improving road safety, e.g. for proper managing.

Roads are generally classified according to characteristics as the motor vehicle volume and/or the traffic speed. Often, this is not done systematically on the basis of a consistent network vision, but just by observing the present situation.

Sometimes, p.e. in Ireland, only a formal classification is given, without much relation to the traffic characteristics.

Whether or not slow traffic is permitted on the main carriageway, especially cyclists and pedestrians, is an important classification criterium for some countries, but in other countries, slow traffic is regarded as 'marginal' or is entirely disregarded.

A positive note is that, in all cases, a distinction is made between roads inside and outside built-up areas.

Anyhow, road users are generally unaware of the classification principle in use. Some hold is only given to them by the actual design of the road, the road signs, the traffic volume and relevant road maps. Because the design of roads with the same function can differ markedly the road user cannot get a clear idea of the road's function by just looking through the windscreen. Therefore, he does not always know accurately how to behave on that road.

It should be realized that, in road traffic, non-professional motorists operate, unequipped with automatic pilot, who are confronted by all types of surprising traffic situations. Not all human errors and mistakes can be eliminated through education, training, information, regulations, police enforcement and penalizing measures. There are untold traffic situations where, each time, traffic participants are misled by the road as presented to them; or by traffic situations where fellow road users come from unexpected directions.

Many roads do also not comply with the requirements for the various road classes. Despite the current planning guidelines, there is no consistent approach in the *design* of roads and junctions, nor in the way parts of the road network are structured. Or, the guidelines are not compelling enough. For example, roads within the same class may be entirely or only partially closed to slow traffic; two-level junctions may be permitted but not always obliged in certain road classes.

In fact, the differences in layout between roads with the same function combination are much greater than the guidelines suggest. Roads with the same functional description can be both single and dual carriageways. Roads for all types of vehicles - the large group of national roads - are very diverse in design. Edge lines may be present or not. Verges and obstacle-free zones are not uniform and are generally not continuous. The recognizability of the function combination of the road and the behaviour in traffic on the basis of the actual layout will therefore leave much to be desired, certainly with roads classified lower in the hierarchical order.

This leads us to an important recommendation: *Road classification can be valuable for safety provided that the classification system is targeted on the safety of the road users only, and is consistently implemented.* For a classification to be effective, the road and traffic characteristics associated with the road classes should represent the correct image to the road users with respect to the driving behaviour anticipated from them.

There is a last, but fundamental shortcoming of existing classification systems. Many times, more than one aspect of the traffic function is supposed to occur on the same road: the roads are *multifunctional*. The same road may have a through function, a distributor function and an access function. As a result of this, the differences between subsequent classes tend to be gradual only, especially if the number of classes is relatively large. Expressing all these differences by introducing easily recognizable distinctions in the shape of the roads is then becoming difficult. Or, the classification is getting a somewhat artificial character which is no longer understood by the road users. In Germany, for instance, 15 classes are distinguished, each of them further subdivided according to a number of features.

A better situation may be reached by adapting an approach that was recently developed: monofunctional road operation.

Monofunctional road operation

The road traffic system had traditionally the task of fulfilling the need for transport by road. This task or function was imposed where possible on the existing road network, even after the marked rise in the number of motorized vehicles. Roads specifically intended for rapid movement, we now call motorways, started to be built in Europe not that long ago.

In the 1970s, when the number of traffic fatalities in many countries reached a record high, road safety measures became a topic. The residential areas were the first to be considered. The safe design of the 'woonerf' was a prominent initiative. This favourable development continued with the 30 km/h zones which are now being introduced in Europe on a broad scale.

On the motorways and in the residential precincts, good results are still gained in reducing the risk to road users. However, there are clearly many roads remaining for which the risks are far more difficult to combat. These roads showing a high accident risk for all modes of transport can broadly be characterized as:
- non-motorway roads outside built-up areas, and
- non-residential streets inside built-up areas.

Current road hazard is predominantly caused by the fact that large parts of the road network are unsuitable for the combination of functions they are expected to fulfil.

It seems quite feasible to adjust the design and regulations associated with a road through a strict allocation of only *one* of the aspects of the traffic function, i.e. either a through function, a distributor function or an access function. This concept comes down to the removal of all function combinations by making all roads *monofunctional*. Research and practical experience over the years have led to the accumulation of sufficient knowledge to allow the practicability of such a classification.

By using three road categories with largely differing characteristics and codes of behaviour, this principle can be met to a significant degree. Each of the categories should match with *only one* of the functions, resulting in pure *through roads*, pure *distributor roads* and pure *access roads*. In that case, there will no more be through traffic on distributor nor on access roads; no more access to properties on through roads nor on distributor roads, etc.

These three functional road categories are not hierarchical and do not differ in importance. Therefore, instead of classification, the term *categorization* is better now.

Depending on the required capacity and on the immediate environment (rural or urban, inside or outside a built-up area) subcategories may prudently be distinguished within each of the three road categories, to be denoted as road types. *The point is to keep the function of the road clear to road users,* despite minor differences in design.

The design standards for the individual road types should, in any case, be based on the three safety principles:
- preventing unintended use of a road,
- preventing large differences in vehicle speed, mass and direction, and
- preventing uncertainty.

The requirements for such a road network can be characterized as strict, p.e. lane separation on all distributor roads. There is a possibility that these requirements lead to designs which cannot be considered realistic. Designs which have no hope of succeeding are better not promoted. It may therefore be necessary at a certain stage of the process to relax certain requirements. But the sound principle of monofunctionality should be kept upright as long as possible.

Thus, a second recommendation on road classification is: *Consider seriously the possibility of monofunctional road operation and try to approach this ideal as closely as possible.*

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METHODS FOR INVESTIGATING THE RELATIONSHIP BETWEEN ACCIDENTS AND ROAD DESIGN STANDARDS

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METHODS FOR INVESTIGATING THE RELATIONSHIP BETWEEN ACCIDENTS AND ROAD DESIGN STANDARDS

ABSTRACT

This paper summarises the alternative methods available for quantifying the relationship between road design standards and accidents. Two methods are described - the before and after method and the cross-sectional approach.

The before and after method relies on identifying trial sites at which design changes are proposed, and obtaining accident data before and after the changes are made. In principle, the effect of the change on accidents is then simply the ratio of the accident frequency (accidents per year) after the change to that before the change. However, in statistical terms a number of complicating factors have to be taken into account. These are: (i) random fluctuations in the basic accident data, (ii) the need to control for systematic changes in accident rates over time, and (iii) bias by selection.

The cross sectional approach relies on obtaining extensive accident, flow and geometric data from a wide range of sites of a particular type and analysing this data to obtain estimates of the relations between accidents and the geometric design variables of interest. This method is a statistical modelling approach. The paper includes a discussion of the data requirements for the cross sectional approach, and describes the form of the model normally fitted.

1. Introduction.

This paper reviews the techniques available for measuring the relationship between accidents and elements of the geometric design of roads and junctions. The safety effects of design standards can only be measured by observing the change in accident numbers which result from differences (or changes) in design. Such differences may be due to changes in design over time, or they may arise from differences in design from place to place. Changes over time may be introduced for a variety of reasons - for example, economics may dictate that a cheaper solution to a particular problem be used in some circumstances, or political pressure may require alternative standards to be adopted - whatever the reason, changes which are made from time to time provide an opportunity to assess the impact that such changes have on accidents. Even if changes are not made, there are often differences in approach to design standards from place to place even within one country and certainly between countries. These differences can also provide an opportunity to study the accident benefits or disbenefits of the alternative design standards being used.

The above paragraph implies that in practice, there are two fundamentally different ways to approach the measurement of the road safety benefits of road design standards - the before/after approach and the cross-sectional approach. These techniques will be considered in the two sections which follow.

2. The before/after approach to safety assessment.

2.1 The basic methodology.

Consider a major road improvement scheme in which higher standards of horizontal curvature are being implemented; some of the sharp bends are being re-aligned so as to have higher radii of curvature and better sight lines. In practice it is quite likely that other aspects of the road design standards are being upgraded at the same time - for simplicity however, we will consider the situation in which only one element in the design is being changed. How shall we assess the road safety benefits of this change in curvature standards? The simple solution would be to compare the number of accidents on the section of road being treated in a period before the changes are made, with the corresponding number of accidents in a period after the changes have been made. So for example, we might record (or extract from the national accident data bank) the number of accidents that have occurred during a period of say 3 or 5 years before the changes were made, then after the changes have been made and a suitable transitional period (say 6 months) has elapsed, we record the number of accidents occurring on the scheme during an 'after' period of similar length to the 'before' period. If the number of accidents in the before period is b, and the number in the after period is a, and the periods are of equal duration, the improvement could be characterised by the ratio a/b; a ratio of 1 would mean no change in accidents had occurred; a change of less than 1 would mean that accidents had fallen and a safety benefit had been achieved.

Unfortunately, there are several technical reasons why such a simple approach is likely to be inadequate. Three will be considered: they are (i) the basic randomness of the accident data (section 2.2 below), (ii) the need to correct for systematic changes over time (section 2.3), and (iii) bias by selection (section 2.4).

2.2 Random fluctuations.

We have already seen that the effectiveness of a road safety improvement can be characterised by the ratio of the number of accidents occurring after the improvement to the number occurring before accidents - a/b - assuming the period over which the accident occurred is the same in each case; we will denote the effectiveness of the scheme by α. We can generalise to different before and after periods simply by writing:

$$\hat{\alpha} = \left[\frac{a}{T_a}\right] \div \left[\frac{b}{T_b}\right] = \frac{a\,T_b}{b\,T_a}$$

where T_a is the duration of the after period and T_b is the duration of the before period.

The problem is that both b and a are unreliable measures of the true long-term accident rate before and after the improvement. The number of accidents occurring in a 3 or 5 year period is a short-term sample of the true underlying mean accident frequency at the site, and as such, is subject to considerable variation. If we could record the number of accidents occurring at the scheme for 1,000 years (or better still 1,000.000 years) whilst everything else remained constant, then we would have an accurate measure of the true accident frequency (accidents per year) at the site. Obviously we cannot do this, so we have to base our estimate of α on the unreliable short-term accident counts we have. Having calculated an unreliable estimate of α in this way, we then have to judge either whether its value is really different from 1 (the no-change value) or whether the value we have obtained would have occurred purely by chance. Put another way, we have to estimate the confidence limits we may place upon the value of α we have calculated. In order to assess whether the value of α is significantly different from 1, it is usual to calculate a statistic denoted by χ^2 (chi-squared). This statistic is:

$$\chi^2 = \frac{(bT_a - aT_b)^2}{(a + b)\ T_a\ T_b}$$

If the value of χ^2 exceeds 3.84 then α is said to be significantly different from 1 at the 5% level - that is to say there is only a 5% (1 in 20) chance that the change in the accident frequency which was observed to occur would have occurred anyway without any real change due to the improvement in design. Significance testing of this kind can be useful if interpreted properly, but it can also mislead by reason of what Hauer calls its 'pernicious nature' (Hauer, 1991a). The fact that a safety improvement has not been shown to be 'statistically significant' does not mean that the effect does not exist - simply that the data has been insufficient to quantify the effect with sufficient precision.

Because of this it is often better to calculate (and quote) the confidence interval of the estimate of α - that is the range of values within which if it were possible to independently repeat the before and after measurements 20 times, one could be sure that 19 out of 20 resulting values of α would lie. This interval is:

$$\hat{\alpha}\ \exp\left[+1.96\ \sqrt{\frac{1}{b}+\frac{1}{a}}\ \right],\quad \hat{\alpha}\ \exp\left[-1.96\ \sqrt{\frac{1}{b}+\frac{1}{a}}\ \right]$$

Supposing then that there were 100 accidents in the 5 year period before the road was improved, and 83 during a similar period after, the value of α would be 0.83, and we would need to test whether this was really different from 1. χ^2 would be 1.57 which being less than 3.84 indicates that the reduction which occurred was not statistically significant at the 5% level (Note: this is **not** the same as saying that no significant (real) difference has occurred). Confusion over the concept of a 'significant differences' can be avoided if the result is expressed in terms of confidence limits as follows: the data shows that the ratio of the number of accidents generated after the improvement has taken place to that before is 0.83 (a 17% reduction) with a 95% confidence range from 0.62 (a 38% reduction) to 1.11 (an 11% increase). Such a statement makes it clear that although the 'best' estimate is that a 17% reduction in accidents has been achieved, the 95% confidence interval includes 1 - so the 17% reduction could be a 'chance' result.

The greater the number of accidents in the before period and the bigger the difference between the accident rates in the before and after periods, the easier it is to demonstrate that the change is statistically significant. However, from the above example it will be appreciated that to demonstrate a real effect convincingly, quite large numbers of accidents are required - and if the anticipated effect is only a few per cent, very large trials must be conducted if reliable estimates of effects are to be achieved. In practice it is usually necessary to use not just one site but many sites in such an experiment. Statistical tests analogous to the ones illustrated above can be used when many sites are included in the study, though there is an added source of variation in that the sites themselves will vary from one to another and the effectiveness of the applied re-design, may not give the same value of α at each site. In this situation, it is probably simplest to use the GLM modelling approach described briefly later in the paper.

To complicate matters still further, it is often the case, that the engineering modifications made to the sites affects not just one design parameter but several - not just, for example, changes in horizontal curvature as suggested earlier, but changes also in the vertical alignment or the visibility distances at some of the key junctions on the route. Whereas the simple statistical approach outlined above (extended to the multi-site situation) can provide an assessment of the accident benefits of a whole package of measures implemented in this way, they cannot estimate the individual contribution to enhanced safety of the various components of the package. To attempt to do this a more sophisticated statistical modelling approach is needed of the kind to be outlined below.

2.3 Correcting for systematic changes over time.

The basic disadvantage of the before/after approach to the assessment of accident changes is that the before and after periods are separated in time. This would not of course matter if other factors remained constant from the before to the after period. Unfortunately, in most situations this will not be the case; there will be a whole range of factors which are likely to change with time. Thus for example, traffic flows will be changing with time - nationally and locally, road user behaviour may change over time, other road safety measures may be implemented during the period of the study, the economic climate may be different, even changes in environmental factors such as the weather may need to be considered. So, some method has to be used to allow for such trends between the before and the after periods.

One possible way of allowing for such trends is to include them directly in the analysis of the data. Thus for example, if the accident data were to be plotted year by year over time, it might be possible to observe the trend over the years and simply detect the step change in the accidents which occurred at the point in time when the new scheme was installed. It may also be possible to allow directly for some of the changes between the before and the after period by constructing a statistical model of the kind to be outlined below which includes explicitly the influence of other co-variables on the before and after accidents.

The method most commonly advocated however - and one which has considerably face-validity - is the use of 'control' sites. The principle is that for every 'trial' site where the improvement is being made, one or more control sites are selected which are not being improved. Any changes over time of the kind mentioned above which may affect the before and after accident numbers is assumed to affect the control sites to the same extent as the improved sites. The changes at the control sites can then be used to 'correct' the apparent effect of the improvement at the trial site (or sites) so as to arrive at an accurate indication of the true effect of the design improvement. Because changes in time are usually the source of concern, accident data on the control sites is obtained for exactly the same period of time as for the trial site - though the before and after periods may not be the same. In this situation the corrected value of α is given by:

$$\hat{\alpha} = \left[\frac{a}{b}\right] + \left[\frac{A}{B}\right] = \frac{a\,B}{b\,A}$$

where b and a are the numbers of accidents occurring at the trial sites in the before and after period - as previously - and B and A are the numbers of accidents at the control sites before and after the improvement. The χ^2 value now becomes:

$$\chi^2 = \frac{(a + b + A + B)\,(bA - aB)^2}{(a + b)\,(A + B)\,(A + a)\,(B + b)}$$

and the 95% confidence limits for the estimate of α become:

$$\hat{\alpha}\,\exp\left[+1.96\,\sqrt{\frac{1}{b}+\frac{1}{a}+\frac{1}{A}+\frac{1}{B}}\,\right],\ \hat{\alpha}\,\exp\left[-1.96\,\sqrt{\frac{1}{b}+\frac{1}{a}+\frac{1}{A}+\frac{1}{B}}\,\right]$$

Consider now the effect of the use of controls on the assessing the statistical significance of an improvement. If we assume that the effect of the improvement on the trial site is just the same as before - ie 100 accidents before and 83 accident after, but now we have a control site (or sites) which generate 200 accidents in the before period and 200 in the after period - clearly the effectiveness of the improvement remains exactly the same at $\alpha = 0.83$. The accidents at the control sites indicate that in this rather unusual case, no correction is needed to the estimate of α. However the value of χ^2 is now only 1.08 - considerably less than before, making the apparent change in accident rate less significant as judged by this statistic. The confidence limits on α have increased, ranging now from 0.58 to 1.18 - considerably wider than before.

The poorer statistical performance of the analysis which includes the control sites arises from the fact that two more variables have been introduced into the calculations - the numbers of before and after accidents at the control sites. These numbers are subject to error just as the numbers of accidents at the trial site are, and the effect of including them is to increase the variability in the calculation of the effectiveness of the treatment. In passing, it is clear from the equations given above that if A and B become very large compared with a and b the value of χ^2 and the estimates of the confidence limits reduce to those given earlier for the case in which no controls are being used.

It is clear from the above analysis, that for control sites to be useful, they must contribute more to the evaluation of the measure being studied than they detract from it due to the added uncertainty they introduce. There are therefore two aspects to the value of the use of controls in before/after studies. The first is the purely statistical: for controls not to introduce excessive variability into the estimates of effectiveness, they must contain large enough numbers of accidents. In many cases this will preclude the use of the same number of sites for trial and controls. The control sites will need to form a considerably larger group. Hauer (1991a) suggest as a rule of thumb, that if the size of the effect expected to arise from the treatment is $100\delta\%$ (ie. a 10% effect would have $\delta = 0.1$ etc.), then the number of accidents in the control period (both before and after) for a perfectly matched control should be between $6/\delta^2$ and $8/\delta^2$ - ie between 600 and 800 accidents. Such controls would often be hard to find.

However the need to include large numbers of sites in a control group highlights the issue of how to choose appropriate controls. The purpose of the control sites is to provide an estimate of what the accident rate at the trial site would have been if it had not been improved. To do this effectively, the control site must behave just as the trial site would have done had it not been treated. That means that control sites have to match the trial site as closely as possible. It is often quite difficult to decide what would make the best control site or sites - and it is equally difficult to devise objective ways of choosing the best. Hauer and his colleagues (Hauer, 1991, and Hauer, Ng and Papaioannou, 1991) have explored the problems associated with the use of controls in the context of accident data from the Canadian states. They illustrate the difficulties of the intuitive selection of the 'best' control for a particular study and Hauer concludes (Hauer 1991a) that 'the use of a comparison group (a control) is a mixed blessing'. He goes on to say: 'comparison groups should not be used merely to satisfy a superficial research etiquette. To account for the effects of weather, driver demography, and norms of behaviour, it is sound practice to use a comparison group if it is sufficiently large. If in a practical circumstance a sufficiently large comparison group is not available, it is better not to use one at all than to use one that is too small. However, in this case the effect of the treatment and that of the unaccounted factors cannot be separated, and this should be explicitly stated in the conclusions.'

2.4 The GLM method.

If before and after studies - with or without controls - involve more than single sites or single periods of time, then the generalised linear modelling methodology provides a convenient way of analysing the data. Such methods are available in computer programmes such as GLIM (Numerical Algorithms Group, 1986, Aitkin et al, 1992) and GENSTAT (Alvey et al, 1977). GLMs can be used to estimate the value of α - the effectiveness of the scheme - suitably corrected for the control site or sites, together with the appropriate statistics for significance testing or for estimating confidence intervals.

In order to use GLMs in this way, the accident data needs to be coded such that the before data is distinguished from the after data using a two level factor, say BA (1 for after and 2 for before) and the trial and control data is similarly distinguished by another factor say, CON (1 for trial data and 2 for control). A GLM 'model' is then set up taking accidents as the Y-variable, with Poisson errors and a Log link (a natural logarithm transform of the accident data), and declaring BA and CON as 2-level factors. Both CON, BA and the interaction CON.BA are fitted to the data as part of the GLM model. In such a model, the coefficient of the interaction term CON.BA is the natural logarithm of the required value if α, corrected for any changes in the control data. Standard errors and values of χ^2 are calculated by GLIM and GENSTAT.

The potential advantage of using GLMs in this way is that not only does the software calculate the statistical information automatically, but the calculation of the effectiveness α in the context of a statistical model. allows other co-variables to be included in the modelling process should this be required. Thus for example, if it is suspected that a time trend occurs in the data, and individual years accident information are available, then a time trend term can be added to the model to calculate the effectiveness of the scheme taking the trend over time into account; other co-variables can in principle be incorporated into the model as well (see for example, Haynes, et al (1993).

2.5 Bias by selection.

It is often the case - particularly when selecting individual accident sites for remedial treatment - that some form of selection criterion is used to choose which sites to treat. So for example, having assembled the accident data from all the sites of a particular kind in a local region, the road safety engineer may decide to select for treatment 'those with more than x accidents in the previous 3 years'. Alternatively, if funds for remedial treatments are limited, the section criterion might be 'select the n sites which have the highest accident frequencies'. Now although the numbers of accidents occurring at a particular site may have a long-term stable average value, the number which occur in a particular period - in the last year say, or the last three years - will be potentially very variable; in some years the number will be high and others it will be low. If, in this situation, the safety engineer chooses some of the high accident sites for treatment, then it is easy to see that purely by chance the year or so following treatment the accidents will have fallen even if the treatment has had no effect whatsoever. This phenomenon is known either as 'selection bias' or 'regression to the mean'.

In this situation, the selection rules determine the size of the regression to the mean effect; whether or not controls are used is also a factor. If the sites were chosen totally at random, then there would be no regression to the mean - the effect only arises because some form of non-random selection process has been used to decide which sites to treat. Even if selection had taken place, provided control sites were chosen using exactly the same rules as those applying to the treated sites, then the correction supplied by the use of the control sites would also correct for regression to the mean. It is easy to see why in practice, neither of these things is done. The safety engineer naturally wants to treat the worst sites first; moreover, he wants to treat all of them and not leave some untreated (as controls) just for the benefit of the accident researcher.

So how could the regression to the mean problem by tackled? Hauer has again done a great deal of pioneering work in this area. In some simple situations, where the selection rules are well defined (and they often are not), Hauer has proposed ways of dealing with this effect (Hauer, 1980, 1986). He has also proposed a more general approach which goes under the name of the 'empirical Bayes method' (Hauer 1983 and 1992). All methods use information from a population of sites corresponding to the ones being treated to calculate a correction to the observed accident rates in the before period - using various smoothing techniques.

The empirical Bayes method derives an unbiased estimate of the before accident rate by combining the observed rate in the before period (b/T_b using the previous notation) with a predicted rate derived from an accident predictive model of the kind described in section 3 below. The accident model is in effect de-biasing the estimate of the observed 'before' accident rate on the basis of information about the population of sites - and in particular their variability. Although it is not appropriate here to consider this approach in detail, its effect can be appreciated from the following expression for the 'corrected' estimate of the before accident rate:

$$r_{corrected} = \frac{r_m(1 + C^2b)}{1 + r_mC^2T_b}$$

where r_m is the accident rate predicted by the model, C is the coefficient of variation of the model predictions (the Standard Error of the model prediction divided by the value of the prediction itself) and b and T_b are as before. It will be seen from the above equation, that when the precision of the predictive model is poor, ie. C is large, the corrected rate approximates to the observed rate b/T_b; when however the accuracy of the model is good, ie. C is small, the corrected rate approximates to the value predicted by the model. The best estimate of α using this method is then simply:

$$\hat{\alpha} = \frac{a}{T_a r_{corrected}}$$

Estimates of the confidence intervals for this corrected estimate which correspond to those given above in the simple case are available.

It has been shown that this approach does indeed remove the bias in the observed accident data and provides a sound basis - in principle at any rate - for calculating an unbiased estimate of the effectiveness of a design improvement or other accident remedial treatment. In fact, if the studies required for the investigation of changes in design standards involve lengths of road rather than the treatment of individual sites, the problem of regression to the mean becomes less serious since the length of road will include a range of features (including junctions) and the scope for bias by selection is thereby considerably lessened. Under these circumstances the effect may be of the order of 1% to 5%. However, regression to the mean is a feature of accident studies which always needs to be considered carefully in the design of the study and its analysis, if the results are not to be open to criticism of bias.

3. The cross-sectional approach to safety assessment.

3.1 Introduction

In section 4.1 above it was suggested that measures of the safety effectiveness of design standards could be obtained from cross-sectional studies. In such studies the relationship between design and safety is deduced from an analysis of the variations in accident frequencies which occur as a result of site to site variations in design. In the UK this technique has been used largely for examining the safety effect of the design of junctions of various types: traffic signal controlled junctions, major/minor priority junctions, and roundabouts. Once relationships between design parameters and accidents have been established, they can be used to predict the contribution of individual design features to safety, or to predict the consequences of changes in design on the expected numbers of accidents.

Cross-sectional studies will normally focus on a clearly and closely defined component of the road network - for example, urban 4-arm traffic signal controlled junctions on two-way single carriageway roads, or roundabouts on dual carriageway roads in rural areas. The approach then adopted is to identify a suitable sample of the junction type of interest on public roads for which accident data is available; the traffic flows and the key geometric variables at these sites are then surveyed, and the resulting data is analysed to obtain accident/flow/geometry relations. The variables which need to be measured are those which will potentially have an effect on accident frequencies. They will include traffic and pedestrian flows, the physical dimensions of the layout, the signal control arrangements (at signalised junctions), and a number of other relevant variables. The numbers of accidents which have occurred at each junction over a reasonable period of time - usually several years - should be available.

The analysis seeks to determine which variables have an effect on the frequency of accidents (the number of accidents per year) and to quantify the magnitude of the effect. From the design standards point of view, such an analysis will indicate those standards for critical design parameters, which would provide an acceptable minimum level of safety. For predictive purposes, the accident/geometry relations, will predict how many more (or fewer) accidents a year would be likely to occur if a particular geometric parameter was changed.

It will be seen from the foregoing description, that the essence of the cross-sectional study is to infer the accident effect of specific geometrical features, from sites in which the geometrical feature of interest has a range of values. A single period of time is involved, so that the problems discussed above associated with the time difference between before and after observations of accident data are avoided. Both types of study (before and after and cross-sectional) can evaluate the effect of design variables on accidents, and both have advantages and disadvantages. The cross-sectional approach is more suited to the determination of the effect of many variables acting together; it avoids the need to physically alter the layouts of trial junctions in order to determine the effect of each variable.

3.2 Recent examples of the application of the methodology

A number of cross-sectional studies aimed at identifying the effects of design variables on accidents have been conducted in various parts of the world. Recent work by Zeeger et al (1988) on the effect of road cross-section design for two-lane roads in the US, and by Leutzbach and Zoellmer (1988) on the relationship between road safety and highway design elements in Germany provide examples of what has been achieved.

In the UK accident/flow/geometry relations have been determined for a wide range of junction types and road links, using the cross-sectional method. Examples are: 4-arm roundabouts (Maycock and Hall, 1984), rural 3-arm major/minor junctions (Pickering, Hall and Grimmer, 1986) and urban 4-arm single carriageway traffic signals (Hall, 1986).

The results of these studies are progressively being incorporated into UK Standards and Advice for road and junction design. The relationships are also being made available in a series of computer programs which are available for use by design engineers. In addition to the accident predictions, the software also includes relationships between the design variables and junction capacity and delay that were developed in the 1970's. These accident relationships are also being used to estimate the expected number of accidents on urban networks so that the effects of changes in the design of urban areas on capacity, delay and accidents can be evaluated.

3.3 The data requirements

3.3.1 Site selection.

In order to determine the effect of particular design parameters on accidents reliably, it is essential to have the full range of values of the important variables represented within as large a sample of sites as possible. If either the range of the variables is limited, or the sample size is too small, then the safety effect of the variables deduced from the analysis may be highly uncertain. This means that large 'stratified' samples are desirable. 'Stratification' means that the sample of sites is selected so that high, medium, and low values of the more important flow and geometric variables are equally represented. The variables most often selected for 'stratification' are the vehicle and pedestrian flows - but the more important geometric variables may also need to be considered. If other features - such as signs or lighting are also of interest, then moderately large subsamples of sites with and without these key features will be needed.

It is good practice in planning a study of this kind to undertake a preliminary survey of about two to three times the number of sites that will be required for the final sample. In this preliminary survey limited data is collected, which includes information on the main features of the sites together with short (15-minute) counts of the vehicle and pedestrian flows. The 'stratified' sample is then selected from these sites.

Sites should also be selected to give a broad geographical spread. Care should be taken to select only those sites that have not been modified recently or subject to unusual changes in flow during the period over which the accident data is to be collected. The sample sizes in the UK studies have typically included 200 to 400 junctions at which between 1000 and 3000 injury accidents have occurred. The maximum sample size has generally been limited by considerations of cost rather than the availability of sites.

3.3.2 Traffic flows.

Traffic flow data should be collected on a weekday, avoiding public and school holidays. Turning flows by class of vehicle should be obtained for a period of at least 12 hours (0700 - 1900). The counts must then be factored to provide an estimate of the flows relevant to the accident period for each type of vehicle and manoeuvre. Pedestrian flows crossing each arm of the junctions should be counted over the same periods of time as the vehicle flows.

3.3.3 Accident data.

The statistical reliability of the accident models is improved if large numbers of accidents are available for analysis. One way of achieving this is to include many years of accident data. It must be recognised, however, that accident rates are likely to change over time, and that time trends may need to be taken into account if an accident period of more than about 6 years is used. A more serious difficulty is that the longer the period studied, the more likely it is that there will have been changes to the layout of the site or to the vehicle and pedestrian flows. For these reasons, it is suggested that the accident period should not be longer than 6 years.

It will be clear from 2.5 above, that no attempt should be made to select sites on the basis of their accident record, since this would lead to 'bias by selection' in the accident models. Moreover, the models should be based on accidents systematically recorded in a national database. In the UK for example, the national system does not record accidents which involve only damage to property, so that the UK models have been based on the injury accidents recorded in the national system.

There is also a need to define the boundary between the components of the road network, and in particular between road links and junctions. In the UK national accident reporting system, junction accidents are those occurring within the junction area itself or within 20 metres along each of the approach roads.

3.3.4 Geometric variables.

After the sample of sites for the study has been selected, the geometric variables that it is intended to examine in the analysis must be selected and defined. Category variables can be used. If, in the simplest case, a group of junctions are designed such that they conform to a small number of layout categories in which all members of each category are geometrically similar, then it may be sensible to treat each layout as a simple category in the analysis.

However, in general, the geometric features of the junctions under study will be far more complex than this - lane widths, path radii, visibility distances, splitter island dimensions and many other geometric properties, will vary considerably from site to site and even from entry to entry. As a result, the geometric properties to be used in the analysis will have to be selected and specified with care. It is certainly essential to include in the analysis all the variables which have been used as part of the criteria for selecting the sample. But it is also important that any inter-correlations between the geometric variables are carefully noted and taken into account in the data analysis and the interpretation of the results. In practice, it is difficult to be confident that a model will reflect the accident/geometry relations satisfactorily unless a wide range of variables - including all the variables that seem likely to affect accidents - have been examined for inclusion in the model. In the UK studies, the numbers of variables were typically of the order of about 100.

Once the relevant geometric variables have been identified and defined, they have to be measured for each junction; it is often possible to do this conveniently from large scale plans - though plans are not always accurate or up-to-date. For each approach arm of the junction, measurements will be needed of road and lane widths, gradients and curvature, the position of road markings, and the nature and position of signs and islands. At roundabouts, the size of the central island and the curvature of vehicle paths as well as sight distances will be needed. Speed limits should be noted. For the traffic signal junctions, measures of the signal control variables need to be obtained: these should include the stage sequences, signal timings, plan schedules for UTC junctions and the presence (or absence) of speed discrimination equipment.

3.4 The modelling process.

Once the data has been collected and verified, the analysis can begin. It is usual to conduct the analysis of the data in stages. First, the characteristics of the accidents are examined by simple cross-tabulation. This provides insights into accident patterns and provides results that are complementary to the main analysis. Subsequently, accident/flow/geometry relations are developed using statistical modelling techniques. In the UK, the generalised linear modelling methodology (McCullagh and Nelder, 1985, Aitkin et al, 1992) which are available using the computer programs GLIM (Numerical Algorithms Group, 1986) and GENSTAT (Alvey et al, 1977) has generally been used. The application of these techniques to junction accident studies is usefully summarised by Kimber and Kennedy (1988).

However, there are alternatives. Techniques equivalent to Principle Components Analysis and Canonical Correlation Analysis for the exploration of complex data sets involving both continuous and category variables have been developed by the State University in Leiden (the techniques are collectively called Qualitative Data Analysis). These techniques can provide valuable insights into the overall structure of the data, and allow optimal transformations of the variables to be explored. The details of these methods are beyond the scope of this paper, and for more details, the reader is referred to Oppe, 1992, where the various methods are compared. For present purposes, the Generalised Linear Modelling method will be illustrated.

3.4.1 Forms of the model.

The general form of the relation is given by:

$$A = k\, Q_a^{\alpha}\, Q_b^{\beta} \exp[\Sigma b_i G_i + \Sigma d_j D_j]$$

where A is the number of accidents per year; Q_a and Q_b are flows, G_i are continuous variables representing the geometric and control characteristics, D_j are dummy variables (taking the values 0 or 1) representing specific design features - for example, the presence or absence of a junction traffic island might have D = 1 *with* the island and D = 0 *without* it; k, α, β, the b_i, and the d_j are parameters to be estimated by the analysis.

Most studies have employed relationships of this general form, although sometimes vehicle and pedestrian flows have been incorporated into the exponential part of the expression, and occasionally, geometric variables have been incorporated as power terms. In the GLM modelling process, the above model is fitted in a logged form. That is to say, the dependent variable A is subjected to a natural log transformation - it becomes ln A, and the right hand side of the equation becomes additive on a log scale. Moreover, the GLM fitting algorithm requires the analyst to specify the error distribution from which the dependent variable is assumed to come; for simple analyses, it is usual to specify a Poisson error structure for accidents.

It is common practice to derive separate accident relationships for different accident types. In a model for single vehicle accidents only for example, Q_a would represent the flow of vehicles and Q_b would not be needed. For accidents involving vehicles from two different traffic streams, Q_a would represent one of the streams and Q_b the other. Similarly, for pedestrian accidents, Q_a might represent the relevant vehicle flow and Q_b the pedestrian flow.

The aim of the modelling is to obtain the best trade-off between the number of variables included in the model and the ability of the model to properly represent the information in the data. The statistical procedures involved in fitting the models are given in detail in a number of the reports listed in the bibliography.

3.5 Illustration of application to design.

In the previous section, the general form of accident /flow/geometry relationships has been considered. It may be useful to present a specific example and to illustrate it's application in design. The example chosen refers to entering-circulating accidents on one arm of a 4-arm roundabout. The relationship is:

$$A_{ec} = 0.046\ Q_e^{0.7}\ Q_c^{0.4}\ k_1\ k_2$$

where A_{ec} is the accident frequency associated with the entry arm (number of injury accidents per year), Q_e is the entering vehicle flow and Q_c is the circulating vehicle flow. All flows are annual average daily totals in units of one thousand. k_1 and k_2 are multipliers. Figure 1 illustrates the relevant variables.

$k_1 = \exp(-0.01\theta+0.2P_m)$ in which θ is the angle between the arm and the next clockwise arm (degrees) and P_m is the percentage of motorcycles in the traffic.

$k_2 = \exp(-40C_e+0.14e-0.007ev-RF)$ where C_e is the entry path curvature (m^{-1}), e is the entry width (m), v is the approach width (m) and RF is the ratio factor. $RF = 1/(1+\exp(4R-7))$ where $R = D/C$. D is the diameter (m) of the largest circle that can be constructed within the confines of the roundabout and C is the central island diameter (m).

From the designer's point of view, it is important to note that A_{ec} is reduced by increasing C_e, ev and RF, and by decreasing e. Some variables have an effect on more than one group of accidents. It is therefore important that the designer take account of the effect of the design variables summed over all accident groups. Figure 2 taken from Maycock and Hall (1984) shows the effect of entry width on all accident groups and on total injury accidents at 4-arm roundabouts. It shows that entry width has a strong effect on accidents when the entry is undeflected. As entry width is increased from 5 to 20m, total accident frequency doubles. Design standards for roundabouts now specify minimum values of entry curvature C_e and maximum values of entry width e for use in design. This illustrates the importance of the effect of the design variables and the role of accident relationships in the setting of design standards.

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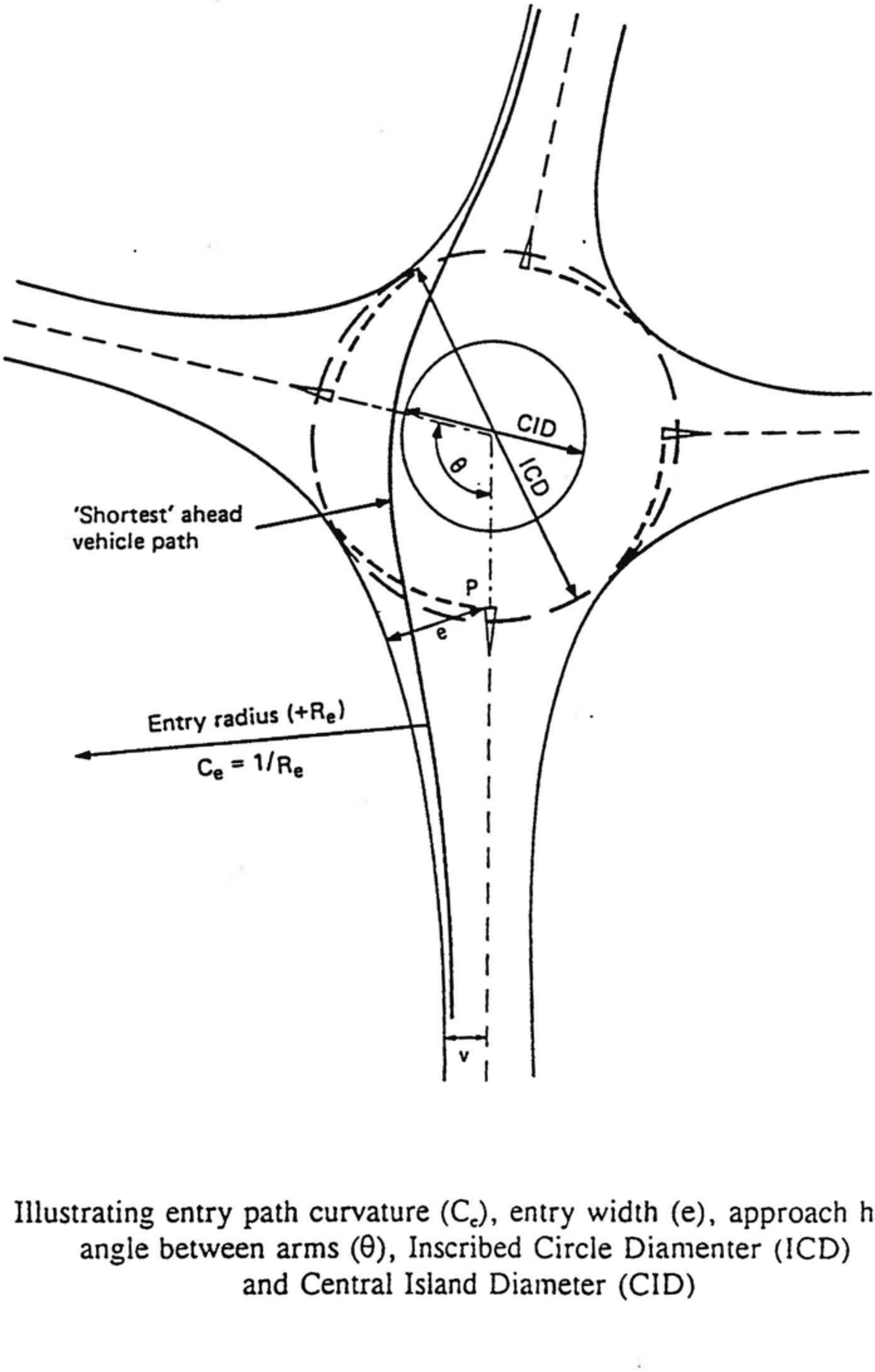
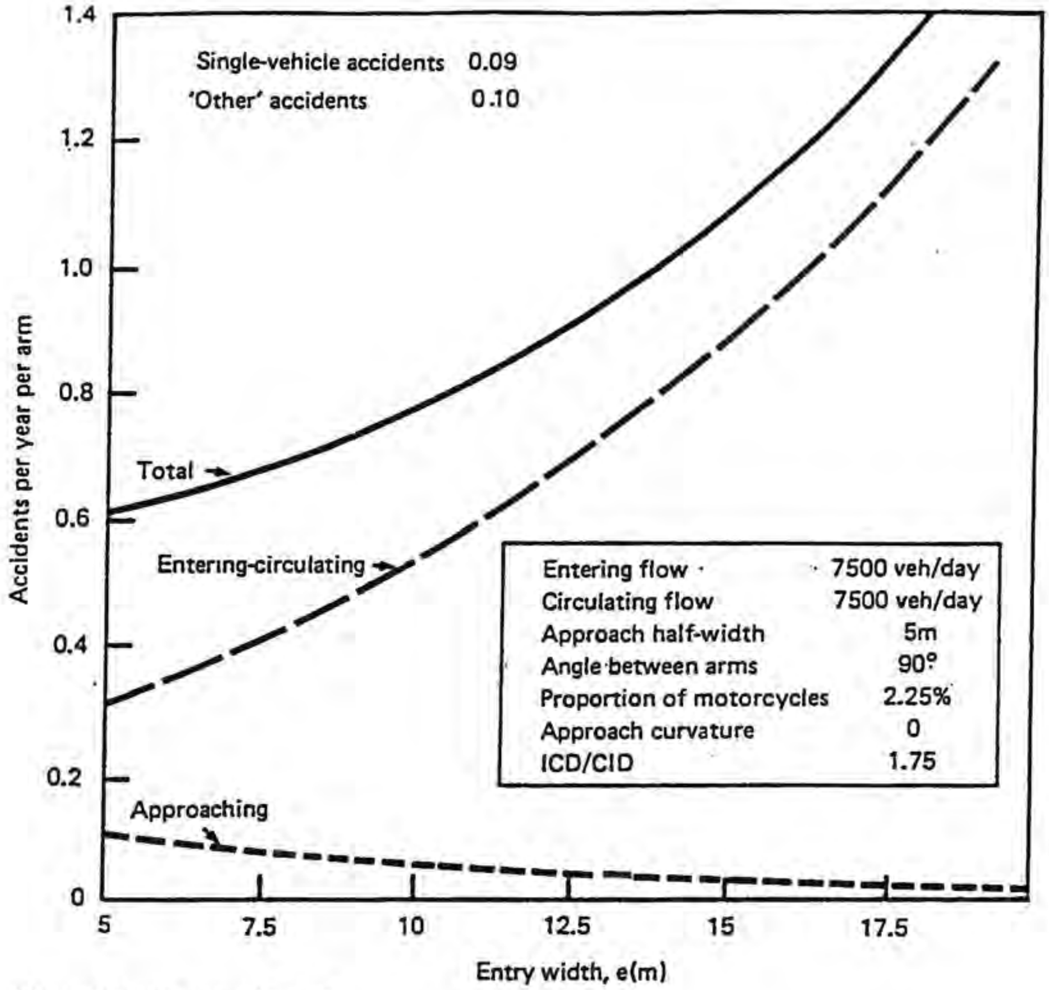
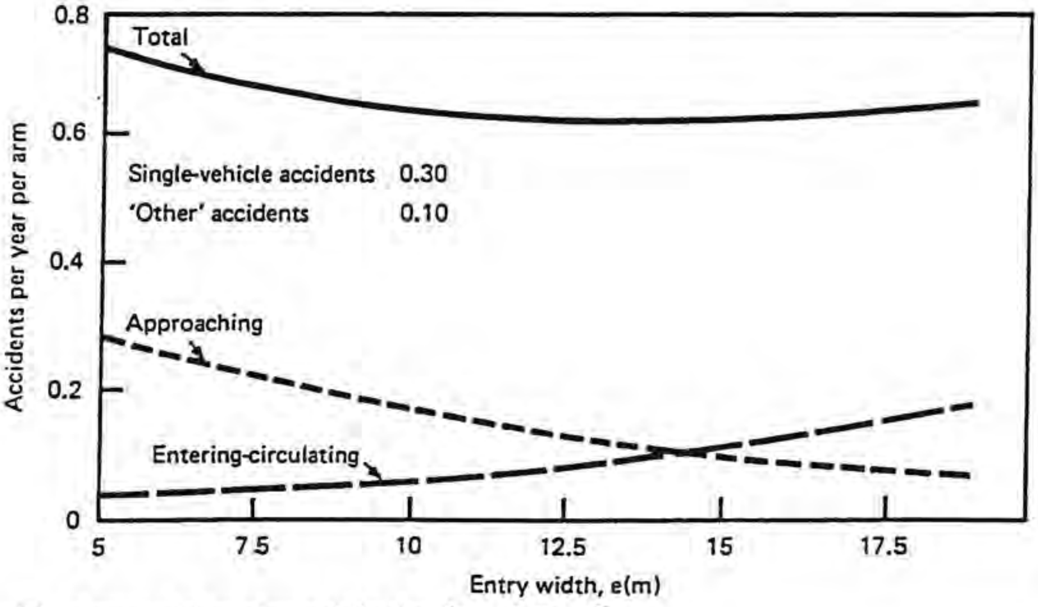


Figure 1 Illustrating entry path curvature (C_c), entry width (e), approach half-width (v), angle between arms (θ), Inscribed Circle Diamenter (ICD) and Central Island Diameter (CID)



(a) Undeflected entry ($C_e = 0$)



(b) An entry with maximum deflection ($C_e = 0.05m^{-1}$)

Figure 2 The predicted effect of entry width on roundabout accidents for a 'deflected' and an 'undeflected' entry

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THE RELATIONSHIP BETWEEN SPEED AND ACCIDENTS

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THE RELATIONSHIP BETWEEN SPEED AND ACCIDENTS

ABSTRACT

The relationship between the traffic speeds on a road and accident rates depends on many interacting factors. Empirical studies aimed at quantifying this relationship are very varied in the type and quality of data collected. However, the evidence available from international studies suggests that for every 1mph change in the mean traffic speed, accidents change in the same direction by about 5%. This paper goes on to demonstrate the effect from two studies recently completed in the UK. The effect of introducing speed enforcement cameras on roads in West London have reduced speeds by 3-6 miles per hour; all accidents have been reduced by 14 per cent and fatal and serious accidents by 36 per cent. In traffic calming schemes introduced into residential areas, speed have fallen by an average of 11 per cent and accidents have been reduced by 65 per cent on average. The paper shows that this latter effect is equivalent to a reduction of between 6 and 7 per cent in accidents for every 1 mile per hour reduction in vehicle speeds.

1. Introduction

The relationship between the distribution of traffic speeds and accident rates on a given road is, as yet, poorly understood. This is not surprising for the relationship depends on many interacting factors. A traffic stream consists of many drivers individually choosing the speed and headway at which they will drive in relation to other vehicles on the road. In their choice of speed an individual driver will be influenced by a large number of factors: the type of road involved, its geometric design, the traffic flow and other environmental conditions and the speeds of other drivers. Individual speed choice also depends on the personal characteristics of the driver - characteristics such as age and driving experience, attitudes to risk taking and to the observance of road traffic law. Speed limits can potentially modify these individuals' choice of speed but the degree to which this happens will be dependent on the perceived level of enforcement.

In addition to variation in speed choice, different drivers will have different accident liabilities - which again will depend on personal characteristics as well as factors such as experience and ability. Furthermore, the geometric and traffic characteristics of roads will make some roads safer per mile than others. The role of speed in accidents both in the aggregate and in the case of individual drivers is therefore extremely complex. What seems intuitively obvious is that the higher the speed a driver drives on a given road the more likely an accident is to occur and the more severe the consequences are likely to be when it does occur. Over the years researchers have attempted to quantify this intuitive relationship.

This paper presents a summary of an international review of the relationship between speed and accidents (section 2), an then goes on to present results from two recent UK studies - the West London speed enforcement camera scheme (Section 3) and the effect on speed and accidents of traffic calming measures in residential areas (Section 4).

2. Review of international research

2.1 The research evidence

The Transport Research Laboratory has recently reviewed the available research evidence for the effect of speed on road accidents. The aim was to gather together the evidence currently available on i) the effect of speed limits on mean traffic speeds and proportion of speeding drivers, ii) the effect of speed limits on accidents, and iii) the relationship between speed and accident risk. Many studies have been reported from a number of countries relating to the introduction of, or changes to, speed limits and the subsequent changes in the numbers of road accidents. These studies are very varied in the type and quality of data collected and in the extent to which they address the complexity of the issues involved. Despite this, current empirical evidence clearly demonstrates that the imposition, or the lowering of speed limits is generally associated with significant reductions in road accidents, and that there appears to be a strong relationship between mean traffic speed and accidents.

In addition to the mean speed, the spread of speeds could be an important determinant of road safety. A few studies have examined the influence of differential speeds on accident involvement rates for individual drivers. There is evidence that the relationship is U-shaped - drivers driving much faster or much slower than the general traffic stream are more likely to be involved in accidents. It has been suggested that overtaking or being overtaken may be the underlying cause of this effect. It is also possible that the U-shaped relationship arises simply because of the different characteristics of drivers in the sub-groups of the driver population at the extremes of the speed distribution.

2.2 Modelling the relationship

Relevant data gathered from several of the better documented studies are shown in Figure 1, which shows the percentage change in the total number of accidents plotted against the absolute change in the mean traffic speed (mph).

As can be seen, much of the key data comes from Scandinavian countries where experimental trials of different speed limits have been closely monitored since the early 1960's. The data covers a range of road types and conditions, where speed limits will have been changed for different reasons, and will have been collected using different techniques, over a period spanning three decades. Despite these, and other limitations facing an international comparison of this kind, a strong positive relationship between mean traffic speed and accidents can clearly be discerned. For the purpose of analysing the data-set shown in Figure 1, the American, West German and Swedish points have been excluded since these results represented the change in fatalities or injury accidents and not the change in total vehicle accidents. The simplest relationship which was considered to fit the underlying trend of Figure 1 was:

$$\Delta A = 4.92 \Delta \overline{S}$$

where ΔA represents the percentage change in the total number of accidents, and ΔS represents the change in the mean traffic speed (in mph).

This relationship is the solid line superimposed on the data in the figure. This relationship suggests that for every 1mph rise in the mean traffic speed, the percentage change in accidents rises by about 5% - alternatively, it predicts a 5% drop in accidents per every mph drop in the mean traffic speed. The observed sensitivity of accident rates to changes in the mean traffic speed is remarkable, and the underlying mechanism for this is not yet understood.

In line with the above findings, American evidence indicates that an increase of only 2 - 4 mph in the mean rural interstate traffic speed has resulted in an **increase** of between 19 and 34 per cent in fatalities. This is a very large effect, suggesting that for every 1mph change in the mean traffic speed there has been an associated change of 8 or 9 per cent in the number of interstate fatalities. Summing up evidence provided by the numerous studies following the raising of the speed limit on American interstate highways (from 55mph to 65mph), Brian O'Neill, president of the Insurance Institute for highway Safety, USA, has remarked that *"there is now overwhelming evidence of the negative effects of higher speed limits in the United States. Although average speeds have only increased slightly, the percentage of motorists travelling at high speeds has increased dramatically."*

A similar result has been observed following speed limit changes on West German motorways, where a 9.7 per cent change in accidents resulted from a 1mph change in mean speed.

3. West London speed enforcement cameras

3.1 The scheme

The West London speed camera scheme was launched in October 1992, and is run by the Metropolitan police. It consists of speed enforcement cameras sited along the principal approach roads in the western sector of London. The criteria for site selection used in the west London speed camera project were: (i) high incidence of speed related accidents, high incidence of serious and fatal accidents, and high incidence of single vehicle accidents involving loss of control.

3.2 Accident reductions from camera enforcement in west London

The speed cameras became operational during the first half of October 1992 at a time when accidents were already declining. In this situation it is very important that the assessment of the accident changes due to the installation of the cameras takes account of these general downward trends. In the present paper, trends are allowed for using accidents in the London Metropolitan Police District (excluding those in the west London camera area) as a control.

Table 1 shows the before and after accidents (fatal plus serious and slight) with the corresponding percentage reduction obtained on two categories of road in the west London area. The two categories of road are (i) the links on which the cameras were installed (termed 'link roads'), and (ii) all other roads. The before period was the 15 October 1991 to 30 September 1992 and the after period 15 October 1992 to 30 September 1993.

TABLE 1

Accidents in West London Speed Camera area plus the A40

Road type	Accident type	Number of accidents		Percentage change After/Before (in relation to control)	Statistical significance* (χ_1^2)
		Before	After		
"Links" ie A4, A30, A312, A316 and A40	Fatal and serious	134	77	-36%	9.79
	Slight	489	461	-8%	
	Total	623	538	-14%	6.31
All other roads	Fatal and serious	679	652	+7%	-
	Slight	3286	3369	+0%	-
	Total	3865	4121	+6%	-
All roads	Fatal and serious	813	729	0%	-
	Slight	3775	3830	-1%	-
	Total	4588	4559	-1%	-
All roads in the Metropolitan Police District	Fatal and serious	6101	5485	-10.1	
	Slight	28645	29339	+2.4	
	Total	34746	34824	+0.2	

* - The significance levels for χ_1^2 are 10% - 2.7, 5% - 3.84, 1% - 6. 64. only those reaching significance at the 10% level or better are given in the table.

The 36 per cent decrease in fatal and serious accidents on the link roads is highly significant. This decrease together with a non-significant 8 per cent decrease of slight accidents, produces an overall decease in accidents on the links equipped with speed cameras of 14 per cent - significant at about the 1 per cent level - that is to say that the probability of this decrease having occurred by chance is about 1 in a 100. Provisional information on traffic speed in West London is currently only available for a few sites, but this indicates that mean speeds have reduced by between 3.4 mph and 6.4 mph. Assuming an average reduction in speed of 5 mph, the above accident reductions correspond for all injury accidents to a reduction of 3 per cent for each mile per hour fall in mean speed, and for fatal and serious accidents a reduction of 7 per cent for each mile per hour reduction in mean speed.

The accident reductions illustrated in Table 1 suggest that enforcement cameras have a significant effect on the roads on which they are installed. However, they have little effect on other roads within the areas. It is clearly important therefore that the sites for the installation of speed cameras are carefully chosen. It would not be very effective for example, to site a camera on a section of road where there are no accident problems. But the use of a speed camera on the approach to a junction with speed related accident problems may have a beneficial effect on the accident rate at the junction.

A more detailed analysis of the data (Table 2) shows that on the link roads, all categories of accidents both at and away from junctions have decreased indicating that the effect of the cameras has been as important at junctions as between junctions. Some of this effect may be due to additional red light cameras which were installed during the 'after' period, but it is not unreasonable to conclude that the overall reduction of speeds on the links has contributed to the reduction in accidents at the junctions as well.

TABLE 2
Accidents on link roads in the West London Speed Control Area
and on all other roads in the area, at and away from junctions

	Away from junctions:			At junctions:		
	Fatal & serious	Slight	Total	Fatal & serious	Slight	Total
Accidents on link roads:						
Before	45	176	221	89	313	402
After	33	152	185	44	309	353
Percentage change:						
After/Before	-27%	-14%	-16%	-51%	-1%	-12%
Accidents on all other roads:						
Before	252	975	1227	427	2311	2738
After	225	1005	1230	427	2364	2791
Percentage change						
After/Before	-11%	+3%	0	0	+2%	+2%

4. Speed and accident reductions in traffic calming schemes

4.1 Introduction

UK highway authorities do not in general undertake rigorous 'before' and 'after' studies whenever a speed limit is lowered or imposed. Some authorities, however, have collected traffic speed, flow and accident data in order to monitor the effect of various traffic calming schemes. Sixteen local authorities which were known to have traffic calming schemes in their areas, were therefore contacted with a view to obtaining data relating changes in speed in these traffic calmed areas to the resulting changes in accidents. Replies containing useable data were received from 8 authorities. This information was used in the analyses described below.

4.2 The data

The dataset used to produce the results which follow contains full information on 63 traffic calmed sites - though only a sub-set of these sites has been used in the analyses presented below. All 63 records contain information on 'before' and 'after' 85th percentile speeds and accident data for three years prior to installation. However, a number of schemes have not been in place for long enough to provide much information after installation. The best case provided four years of accident data after implementation, while the worst case provided only five months of data. Data on the flow of traffic in the traffic calmed areas was not available for a variety of reasons.

Information was also collected describing the type of traffic calming measures used in each scheme. It was found that most schemes used road humps, although a number used more than one measure. For example, schemes may include road humps and chicanes, road humps in a 20mph zone or road humps combined with road narrowings.

The speed data that have been used in this analysis are the 85th percentile speeds, which is the speed measure collected by most authorities. This will be closely related to the mean for the speeds that are recorded here. If speeds were normally distributed, the 85th percentile will be the mean + 1.036 multiplied by the standard deviation. Analysis of a set of typical urban links suggests that the standard deviation for the calmed roads will be in the region of 4 mph, so that the mean speeds at these sites will be approximately 4 mph lower than the 85th percentile speeds presented below..

4.3 Results

In all cases the speed data shows that the traffic calming schemes have achieved a reduction in traffic speed. However, there was one reported instance where the speeds have increased on a section of road following a stretch of traffic calmed road; this is possibly due to drivers attempting to compensate for having to slow down for the road humps. The actual change in 85th percentile speed and the percentage change in number of accidents per annum were calculated from the raw data. It was found that the mean change in 85th percentile speed was a reduction of 10.6 mph with a standard deviation of 4.9 mph. The mean of the percentage change in number of accidents per annum was a reduction of 64.9 per cent.

Two analytical methods have been used on the data. Section 4.3.1 below describes an analysis based on the differences in the before and after speeds and accidents carried out using simple least squares regression. Section 4.3.2 describes an analysis using the Generalised Linear Modelling methodology applied to the raw accident and speed data from the traffic calmed sites.

4.3.1 Least squares regression analysis

The analysis using least squares regression reported in this paper relates to a subset of 54 sites. This subset excluded data from schemes which had less than 12 months accident data and/or used other measures in conjunction with road humps. The best fitting regression line through the origin was:

$$\Delta P = 5.14\ \Delta S$$

where ΔP and ΔS are as before. This is shown in Figure 2 as the solid line with the 95% confidence envelope shown by dotted lines (95% confidence intervals of the slope are: 4.13, 6.15)

4.3.2 Generalised Linear Modelling

The number of accidents occurring in a specified period of time can be often be treated as if it had been drawn from a Poisson distribution whose mean is the mean of all such accident numbers averaged over all the sites included in the sample. This fact prompted further investigation of the data using the Generalised Linear Modelling (GLM) methodology implemented in the GLIM package. For this purpose a data set was compiled which consisted of the following variables and factors:

N	Number of accidents occurring before or after the implementation of the traffic calming scheme,
T	The time period in years corresponding to the accident numbers N,
S	The 85th percentile speed corresponding to the accident numbers (before or after) N,
BA	A 2-level factor indicating whether the data related to a 'before' situation (BA = 1) or and 'after' (BA = 2),

The full data set thus consisted of 126 cases (data corresponding to 63 sites 'before' the installation of the traffic calming measures and 63 corresponding to the 'after' data). A model with Log link and a Poisson error structure was then fitted to the whole data set and to a data set in which two sites with particularly high accident frequencies were omitted, to explore variation *within* the data. In its logged form the model fitted was:

$$\ln(N) - \ln(T) = \beta_0 + \beta_1(S) + \beta_2(BA)$$

Where N, T, S and BA are defined above, and the β's are the coefficients to be determined.

The coefficients of the best fit model for the data set which omitted the two high accident sites are given with their standard errors in Table 3. (The inclusion of the two high accident sites makes little difference to the result, but the actual values of the estimated coefficients will then be heavily dependent on those two particular sites.)

TABLE 3

Models of accident frequencies at traffic calming sites (excluding 2 high accident sites)

	Coefficient	S.E.
Best Fit Model:		
Ln[Constant] - (β_0)	-1.699	0.591
Speed, S - (β_1)	0.066	0.016
Ln[BA] - (β_2)	-0.611	0.319
Speed Only Model:		
Ln[Constant] - (β_0')	-2.448	0.450
Speed, S - (β_1')	0.085	0.013

It will be seen from Table 3 that the statistical significance of the before/after factor is marginal, so that statistically speaking, this term could be dropped. The lower half of Table 3 shows the values of the parameters β_0', and β_1', of a model which includes only S (the 85th percentile speed). In this model, only speed differences are allowed to explain the between site differences in the before and after accidents numbers.

The best fit model appropriate to the data set excluding the two high accident sites, explains approximately 40% of the non-Poisson variation within the accident counts. This means that there is considerable unexplained variation in the accident data which cannot be attributed to either the effect of the explanatory variables or to the basic Poisson error structure of the accident counts themselves. The standard errors in Table 3 have been adjusted (upwards) to take account of these non-Poisson errors.

A supplementary analysis showed that the speed effect *within* the before data although larger than *within* the after data was not significantly so; a common speed effect is therefore justified. For the model excluding the two high accident sites, the models can be written:

$$A = 0.183 \exp(0.066\ S) \times [1,\ 0.543]$$

$$A' = 0.086 \exp(0.085\ S)$$

Where A is the accident frequency (accidents per year) predicted by the model which includes the BA factor and A' is the corresponding values for the model which includes speed only. In the first equation, the BA factor is given in square brackets. It is 1 in the before situation and 0.543 in the after - indicating that its effect is to reduce 'after' accidents by some 46 per cent in addition to reduction generated by 'after' reductions in speed.

The exponential model for speed enables the results shown in the above equation (that including the BA term) to be simply represented in the 'differential' form. Differentiation of the equations with respect to S (speed) provides the relationship:

$$\Delta P = 6.6\ \Delta S$$

where ΔP and ΔS are as before. Thus the effect of speed on accidents demonstrated by this analysis is that accidents have decreased by between 6 and 7 per cent for every 1 mile per hour decrease in speed. This result is remarkably close to the overall average effects calculated by the classical regression method given earlier strongly suggesting that the main cause of the reduction in accidents at these sites are the speed reductions brought about by the traffic calming measures.

This conclusion is confirmed by comparing the effectiveness of the speed and BA terms in the above models in predicting accidents. Table 4 compares the observed and predicted accident frequencies before and after the introduction of the traffic calming measures at speeds corresponding to the mean before and after speeds.

TABLE 4

Comparison of observed and predicted accident frequencies.

	Before	After
Accidents per year:		
Observed	1.86	0.48
Predicted (A) - Best fit model	1.76	0.47
Predicted (A') - Speed only model	1.61	0.64
Mean Speeds	34.29	23.49

It will be seen from Table 4 that the model using speed only reproduces the differences between the before and after accidents quite well - thus indicating that the speed term is providing the majority of the explanatory power of the model. However, the additional term BA does provide some additional explanation, suggesting that some - probably most - of the factor of 0.543 attributed to the BA factor in the equation given in Table 4, arises from before/after effects other than speed. Figure 3 shows the model fit to the data (excluding the two high accident sites), split into 'before' and 'after' categories.

5. Conclusions

The review of a wide range of international studies relating changes in mean speeds with the resulting changes in accidents has shown that a 1 mph reduction in speed can result in a 5 per cent reduction in accidents. If as in the US example, where speed limits on interstate highways were raised, and as a result traffic speeds increased, then accidents will increase also.

The implementation of a camera enforcement scheme in West London reduced mean speeds on the main roads in the area by about 5 mph. All injury accidents in the year following the initiation of the speed control scheme, fell by 14 per cent and fatal and serious injuries fell by 36 per cent. Although these reductions are not quite as large as the 5 per cent for each 1 mile per hour reduction in mean speed suggested by the international review, they are still considerable.

The relationships between change in speed and percentage change in accidents for traffic calmed roads are remarkably consistent with the relationship derived from the international study. In traffic calmed schemes 85th percentile speeds fell by an average of about 11 mph while accidents fell by 65 per cent. Although some of this reduction in accidents would seem to have been due to effects other than speed, but the majority of the accident reduction is associated with the reduction in speed. In these schemes, accidents fell by 6.6 per cent for each 1 mph reduction in speed.

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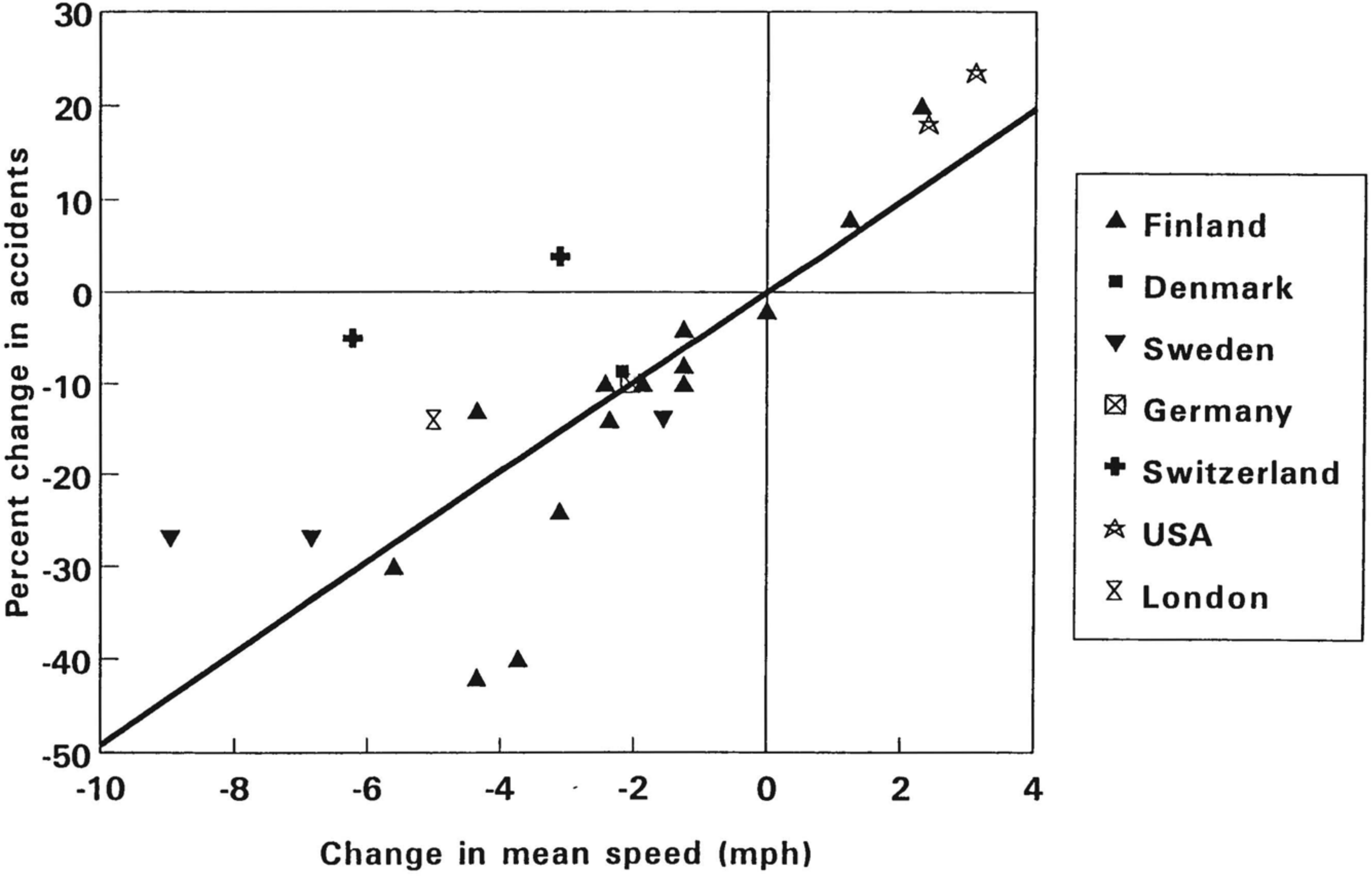

Fig. 1 International studies showing changes in accidents resulting from changes in mean speed

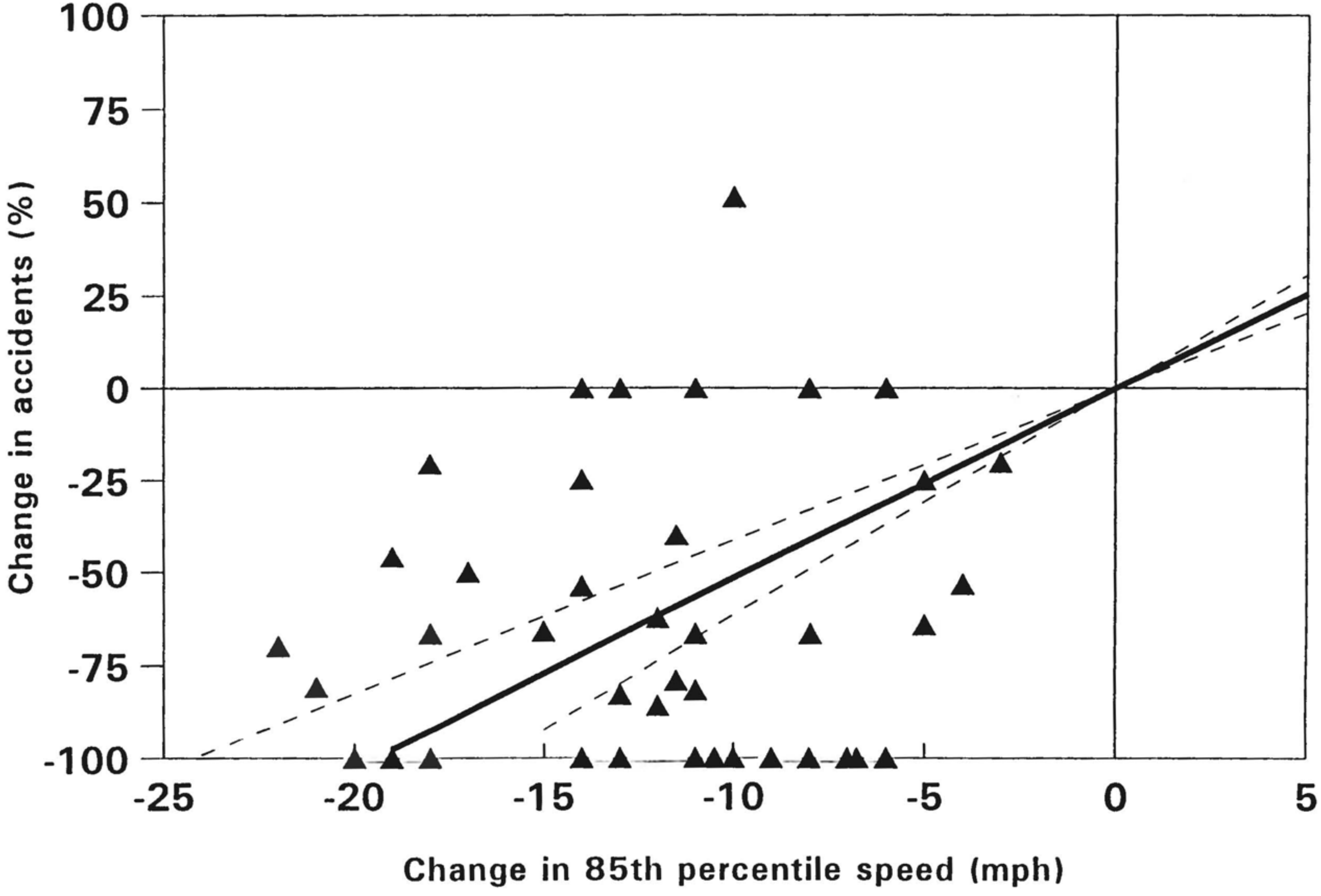

Figure 2. Relationship between speed and accidents for traffic calming schemes with greater than 1 year of accident data

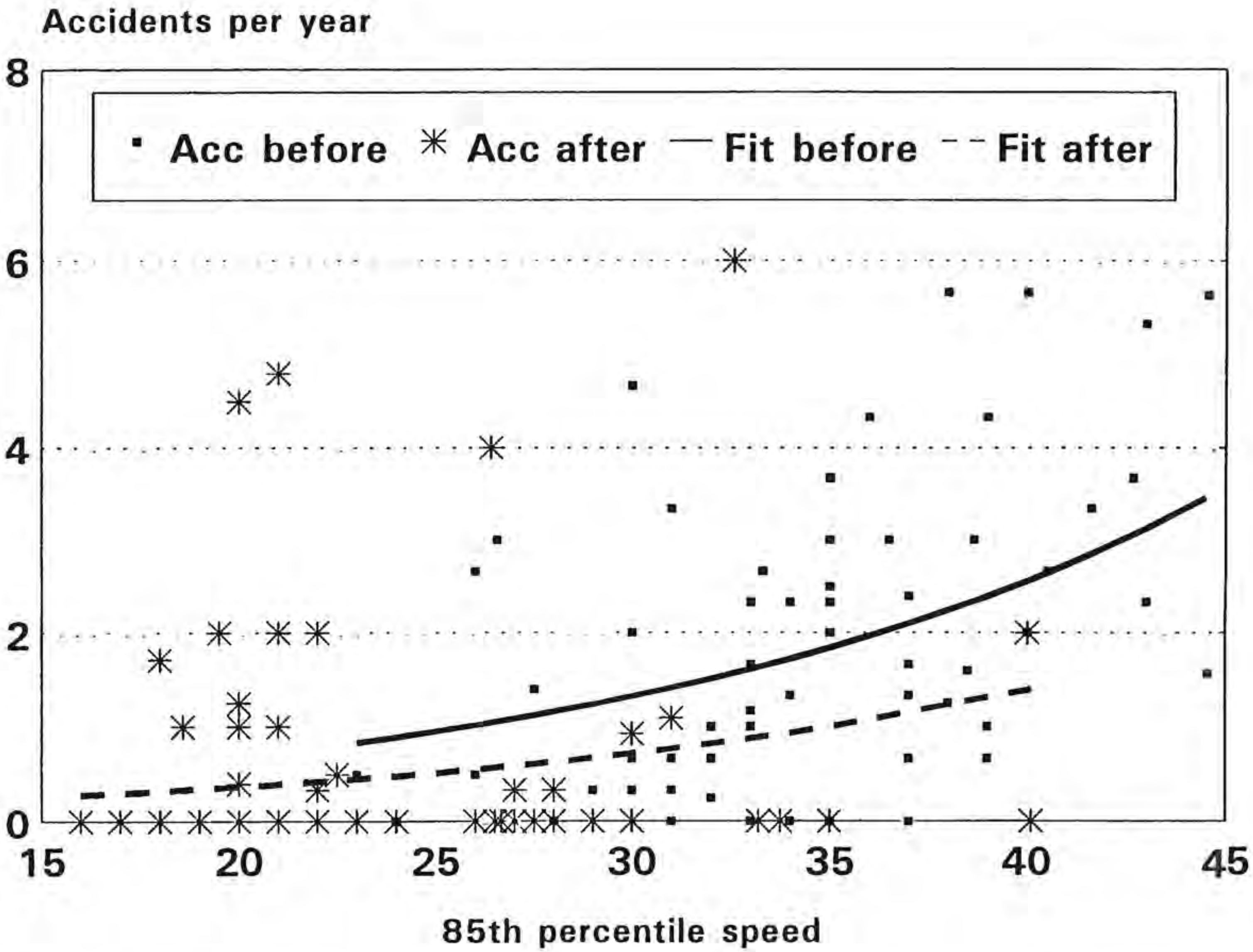

Fig. 3 Traffic calming before/after data showing model predictions

DESIGN OF MOTORWAYS AND RURAL ROADS WITH SPECIAL EMPHASIS ON TRAFFIC SAFETY

by

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ABSTRACT

For modern highway geometric design of two-lane and multiple lane rural- as well as suburban roads qualitative and quantitative safety issues are proposed.

The study consists of five steps:

1. The fatality situation in Europe and the United States was analyzed in order to show "Where people died?" and "Who died?".

2. Utilization ratios for maximum permissble side friction factors were developed for different road categories, topography levels, as well as maximum and minimum superelevation rates.

3. The resulting experiences revealed, that about 50 % or even more of the fatalities can be attributed to two-lane rural highways and at least half of them to curved roadway sections and the corresponding transitions.

   Therefore, three Safety Criteria for Modern Highway Geometric Design Guidelines were developed, in order to alleviate the accident risk at the above mentioned critical locations. The quantitative classification of the three Safety Criteria is based:

   - on the experience of Criterion I, that the driving behavior of motorists, expressed by the absolute difference of the 85th-percentile speeds between successive design elements should fall into certain ranges (achieving consistency in the alinement).

   - on the experience of Criterion II, that considering individual design elements the absolute difference between the observed 85th-percentile speed and the design speed should correspond to certain ranges (harmonizing design speed and operating speed), and

   - on the experience of Criterion III, that in curved sections the difference between geometry assumed side friction and side friction demand should also correspond to quantitative ranges (providing adequate dynamic safety of driving),

   when evaluating "good", "fair", and "poor" design levels. Corresponding evaluation backgrounds for operating speeds and side friction factors were developed for modern highway geometric design exemplarily.

4. To identify potential safety errors for new designs and redesigns a procedure is presented, based on the three individual Safety Criteria. The procedure is explained by a case study, how to transfer unsafe sections of old alinements into an overall sound curvilinear alinement, which represents only "good design levels".

5. The three proposed Safety Criteria were combined for the first time in a Safety Module for evaluating whole road networks by using Geographical Information Systems.

6. Important Standard Cross Sections are presented.

1. HISTORICAL DEVELOPMENT OF ALINEMENT DESIGN PROCEDURES

Alinement design procedures are influenced primarily by the experience and education of the highway design engineer. The development started with simple polygon sections to describe horizontal alinements, which were then based on circular curves. Finally, alinements were developed by the standard elements "tangent (straight), transition curve (clothoid or spiral) and circular curve" in the horizontal alinement and by the elements "tangent, circular curve and quadratic or cubic parabola" in the vertical alinement. Generally, an early incorporation of the vertical alinement into highway geometric design and mutual tuning with the horizontal alinement is adopted today.

Figure 1 shows the development, over time, of alinement design:

1) Tangent and circular curve.

2) Tangent and circular curve with transition curve (circular curve with double radii of curve as transition curve).

3) Tangent and circular curve with transition curve (clothoid or spiral, cubic parabola, etc.)

4) Alinement as 3), but without any interim tangent.

5) Three dimensional alinement with superimposed distortion points as 4) but including the vertical alinement. This could be called an ideal "Curvilinear Alinement".

It follows that the exact evaluation of road characteristic is one important step for designing consistent and understandable curvilinear roadway sections. In this connection <u>two-lane rural</u> road safety is an issue of pressing national concern in Europe and the U.S.A. These roads have the highest accident rate of any class of highway, with fatal and injury per vehicle-km exposure accident rates consistently being four to seven times higher than those on rural interstate highways.

Even though design speed has been used for several decades to determine allowable horizontal alinement, it is possible to design certain inconsistencies into highway alinement especially on two-lane rural roads. At low and intermediate design speeds, the portions of relatively flat alinement interspersed between the controlling curvilinear portions may produce operating-speed profiles that may exceed the design speed in the controlling sections by substantial amounts. This is true for transition sections between successive design elements (for example: tangents to curves) and for the observed individual design element (for example: the curve itself).

To overcome this weakness in current practice consideration of curvilinear alinement becomes of significant importance.

In addition cross section features are very important for the road characteristic besides the alinement elements. One of the strongest impacts on traffic safety is for example the fact, that whether a road is separated directionally by a median or not. A separation by a median produces a quality jump for traffic flow and safety. For multiple lane divided highways combined with grade-separated intersections it can be estimated that

- the personal injury accident rate is less than half, and
- the fatality rate is only one quarter,

as compared to those of two-lane highways with at grade intersections. Therefore, many of the following considerations are primarly concerned with two-lane rural roads.

2. HIGH RISK TARGET LOCATIONS AND AGE GROUPS

The tragic but real consequence of traffic accidents continues as one of the world's most current examples of irresponsible social behavior. People need to be made aware of, and assume responsibility for the possible effects of their driving behavior on themselves and on others. This lack of awareness and responsibility may be an important reason why more than 1/2 million people are killed in vehicle accidents each year. Of the millions who are injured, hundreds of thousands are maimed for life. Therefore, let us ask, where do people die?

The above numbers seldom appear in a newspaper or in a TV bulletin, but they actually summarize what happens in one year worldwide. A single airline crash, or maritime disaster, is front page news and prompts a federal investigation. But, death in a traffic accident remains, for the most part, an invisible slaughter.

Figure 2 reveals fatality distributions for different road categories in selected countries.

According to this figure it can be estimated, that about 50 % or even more of the fatalities can be attributed to two-lane roads outside of built-up areas, and at least half of these serious accidents occur on curved roadway sections. For example, considering that at least for Germany 57 % of the rural fatalities were caused by run-off the road accidents - the typical accident type for curved sites - this would mean, that on the rural road type (in the majority of cases: two-lane)

$$0.57 \times 0.55 = 0.31 \rightarrow 31\ \%$$

of the fatal accident situation occurs at curved sites. Nearly the same ist true with regard to serious injuries.

Thus curved sites represent one of the most critical locations for answering the question "Where do people die?" and when considering measures for reducing accident frequency and severity.

Multiple lane highways, on the other hand, are much safer. For example, the American "Interstate" and the comparable German "Autobahn" system represent with about 10 % of the total number of fatalities the safest road class (Figure 2), even though 25 % of the vehicle-kilometers driven are normally done on these roads. Multilane highways normally are designed very generously, that means curvilinear aspects are already more or less regarded for the design of these roads.

Figure 3 reveals the distribution of fatalities by age-groups for selected countries. As can be seen, young drivers aged 15 to 24 are endangered in large part in all refered countries, due to excessive speed and often because of their lack of driving experience.

This age group represents on the average 28 % of all fatalities in Europe and the U.S.A., although the proportion of the population is only about 16 % in both continents. If follows, that the percentage share of fatalities for this age group is roughly twice this figure. Note, that in several countries the fatality percentage of the age group > 64 years is also relatively high with regard to the population proportion. Therefore, with regard to the question "Who dies?" always the age group "15 - 24" and often the age group "> 64" are highly endangered.

3. CURVED ROADWAY SECTIONS

The previous statements proved, that first of all two-lane rural roads reveal the highest accident risks and severities. Therefore, this portion of the road network should be regarded with special emphasis, when designing, redesigning, as well as conducting restoration, rehabilitation or resurfacing (RRR-) projects for these roads.

The safe and efficient movement of traffic is greatly influenced by the geometric features of the highway. A review of accident spot maps normally shows that accidents tend to cluster on curves, particularly on very sharp curves. Even though the design engineer possesses detailed information - derived from driving dynamic formulas and standard values - on driving through a curve, accident frequency and severity often appear to not coincide with the actual driving behavior. Many of these speed errors may be related to inconsistencies in horizontal alinement that cause the driver to be surprised by sudden changes in the road's characteristic, to exceed the critical speed of a curve and to lose control of the vehicle. These inconsistencies can and should be controlled by the engineer, when a roadway section is designed or improved.

In conclusion of the newest research work in this field, it is stated about the relationship between accident situation and "radius of curve" by Choueiri, Lamm et al. [1, 2]:

- Significantly higher curve accidents occur at sharper curves.
- The accident risk (expressed through the accident rate) and the accident severity (expressed through the accident cost rate) decrease with increasing radius of curve.

- Road sections with radii less than 200 m have an accident rate which is at least twice as high as that on sections with radii greater than 400 m.

- A radius of 400 m provides a cross-point in safety.

- For radii greater than 400 m, the gain in safety is relatively small.

- The same radius of curve in a sequence of similarly tuned radii can have effects on the accident situation other than those in a non-tuned sequence of different radii, as is usually the case on most old alinements, where especially "isolated curves" between long tangents are very dangerous.

However, the horizontal alinement of the road is not solely characterized by the radius of the curve.

To evaluate quantitatively curve design in the future, three safety criteria were developed by Lamm et al. [3-7] in order to

- achieve operating speed consistency,
- design consistency, and
- driving dynamic consistency.

But before these three safety criteria will be discussed, sound driving dynamic assumptions for tangential and side friction factors will be established.

4. ESTABLISHMENT OF PERMISSIBLE FRICTION FACTORS

Recent research has emphasized, that sufficient friction supply is to be regarded as an important safety issue [8-11]. The roadway should provide a level of skid resistance for safely accommodating the braking and steering maneuvers, which can reasonably be expected for the particular site and a skid resistant pavement surface is one key element in the prevention of skidding accidents.

To alleviate this problem several countries have established evaluation backgrounds for the distribution of skid-resistance in their road networks, in order to relate the maximum permissible friction factors to the 90th- or 95th-percentile distribution curves of these backgrounds. In this way the overwhelming majority of road surfaces is covered, for example Germany uses the 95th-percentile distribution curve of Figure 4 as basis for the assessment of maximum permissible tangential friction factors.

4.1 Tangential Friction Factor

For most countries those skid-resistance evaluation backgrounds like on Figure 4 do not exist so far. Therefore, an overall regression relationship between tangential friction factor and design speed was established in [12], based on the assumptions for maximum allowable tangential friction factors for the Federal Republic of Germany, France, Sweden, Switzerland, and the U.S.A. (see Figure 5). The developed overall tangential friction regression curve and equation are presented in this figure. This relationship was compared with actually existing skid-resistance inventories in Germany and the U.S.A. and is considered today as reasonable for safety, economic, and environmental demands. Therefore, the equation on Figure 5 may be used in modern Highway Geometric Design Guidelines for determining stopping sight distances and radii of crest vertical curves.

4.2 Side Friction Factor

After the establishment of the relationship between the maximum permissible tangential friction factor and the design speed, the question arises in which range the utilization ratio "n" of the maximum permissible side friction factor shall be selected. Based on international experience, this value varies between n = 40 % and n = 50 % for rural roads. This means, that 92 %, respectively 87 % of friction in the tangential direction is still available, when riding through curves for acceleration, deceleration, braking or evasive maneuvers [11, 13, 14, 15].

In this way the equation for the maximum permissible side friction factor is given in its general form according to Table 1 as:

$$f_{Rperm} = n \times 0.925 \times f_{Tperm} \qquad (1)$$

The reduction factor of 0.925 corresponds to tire-specific influences [11, 15].

4.3 Arrangements for Different Topographic Levels and Road Categories

4.3.1 Rural Roads

Based on the specific topographic conditions in many countries (flat, hilly and mountainous topography) different utilization ratios were considered as reasonable for the side friction factors for the category group "Rural Roads".

Flat Topography, Maximum Superelevation Rate (Rural)

In flat topography and/or snow-free areas an utilization ratio of n = 45 % is justified for the application of maximum superelevation rates of e_{max} = 8 % (9 %), based on practical experience in several European countries. The relationship between maximum permissible side friction factor and design speed is graphically/presented as curve (3) in Figure 6. The corresponding equations (2a) and (2b) can be found in Table 1. For comparitive reasons the relationship for the maximum permissible tangential friction factor and the design speed is given as curve (1).

Hilly and Mountainous Topography, Maximum Superelevation Rate (Rural)

For hilly and mountainous topography a utilization ratio of n = 40 % for maximum superelevation rates of e_{max} = 7 % is considered as reasonable, in order to compensate from the driving dynamic safety standpoint the decrease in superelevation rate through a lower utilization ratio. The relationship between maximum permissible side friction factors and design speed is represented through curve (4) in Figure 6 and the equations (3a) and (3b) in Table 1.

Using the utilization ratios of side friction of n = 45 % for flat topography and of n = 40 % for hilly/mountainous topography, there is still 90 %, respectively 92 % available for friction in the tangential direction, when driving through curves.

Minimum Superelevation Rate (Rural)

Besides the establishment of utlization ratios for determining permissible side friction factors, when implementing maximum superelevation rates, the evaluation of a justified utilization ratio is also very important when implementing minimum superelevation rates. Fundamentally, the assumptions of utilization ratios stem from considerations about danger classes [16] in such a way, that for smaller superelevation rates the utilization ratio "n" can be selected at a lower level.

For the overwhelming majority of all investigated countries with the exception of the U.S.A., the minimum superelevation rate is selected to be equal to that in tangents because of drainage and driving dynamic safety requirements and corresponds to the value of $e_{min} = 2.5$ %. In this case a utilization ratio of n = 10 % is considered as reasonable [13, 16]. The relationship between the side friction factor and the design speed is for all topography classes represented through curve (6) in Figure 6 and equations (4a) and (4b) in Table 1.

4.3.2 Suburban Roads

For the category group "Suburban Roads" it can be expected that the speed level is normally lower than on roads for the category group "Rural Roads". Therefore, a higher utilization ratio of the side friction factor can be tolerated in respect to driving dynamic safety considerations and is urgently requested due to economic, environmental and municipal development reasons.

Maximum Superelevation Rate (Suburban)

For suburban roads a maximum utilization ratio of n = 60 % for e_{max} = 6 % is justified [16, 17]. In this case 80 % of friction is still available in the tangential direction, when driving through curves. Curve (2) in Figure 6 and equations (5a) and (5b) in Table 1 represent this case.

Minimum Superelevation Rate (Suburban)

Because of the expected lower speed levels on suburban roads in contrast to those of rural roads for the application of minimum superelevation rates e_{min} = 2.5 % a higher utilization ratio of the side friction factor also appears to be justified and is selected according to the German Guidelines [13, 16] to n = 30 %. The relationship between side friction factor and design speed is given through curve (5) in Figure 6 and equations (6a) and (6b) in Table 1.

An exact listing of the maximum permissible tangential as well as side friction factors is given in Table 2 with regard to the design speed, the road Category Groups "Rural" and "Suburban", for the different topography classes as well as for the recommended maximum and minimum superelevation rates.

Futhermore in Table 2, the respective minimum radii of curve are calculated based on the driving dynamic formula for curve design (equation 7) with regard to the newly developed side friction factors in combination with the as reasonable considered maximum and minimum superelevation rates.

A comparison of Table 2 with several existing Highway Geometric Design Guidelines reveals that for higher design speed levels the differences in the calculated R_{min}-values are relatively small, while for lower design speed levels the values in

Table 2 are often higher than those of the other guidelines. This is reasonable, especially since lower design speeds are often exceeded by sustantial amounts, as was observed in all studied countries.

Therefore, to differentiate utilization ratios of side friction for individual road categories, topography classes as well as for maximum and minimum superelevation rates appears justified, since such a differentiation provides logical driving dynamic safety reserves there, where they are mostly needed. Additionally, considering maximum permissible side friction factors for minimum superelevation rates also completes the overall driving dynamic design process.

In this study maximum and minimum superelevation rates were selected based on international experience and the sometimes used values of e_{max} = 10 % and even e_{max} = 12 % were consciously not considered in recognition of the combined controls of construction processes, maintenance difficulties and the operation of heavy vehicles at low speeds, for example under snow and ice conditions.

Fundamentally the developed maximum tangential and side friction factors consider important safety aspects. These will affect the proper dimensioning of the design elements knowing that certain qualitative safety reserves are present. But so far nobody can examine quantitatively a level of "Safety" or "Un-Safety" at curved sites. Therefore, the development of quantitative Safety Criteria is the next important step.

5. THREE QUANTITATIVE SAFETY CRITERIA IN HIGHWAY GEOMETRIC DESGIN

Research studies and design guidelines agree that by limiting the changes in operating speeds - expressed through the 85th-percentile speeds - between road sections to certain ranges, it can be determined whether the break in the speed profile is acceptable, or may cause a speed change that could lead to critical driving maneuvers. Research studies also indicate that the design speed and the 85th-percentile speed (V85) on wet pavements must be well balanced to ensure a fine tuning between road characteristics, operating speed, and driving dynamics. For instance, studies have shown that the design speed concept allows to build in critical inconsistencies into the horizontal alinement, for example between the flatter and sharper portions of the highway, when the controlling horizontal curves sometimes correspond to an arbitrarily selected design speed. In these cases, transition sections may exist, requiring unexpected critical speed changes from the driver, which may in turn lead to hazardous driving maneuvers. In addition, a tendency exists for some drivers to travel faster than the design speed on which the original design of the road section was based by substantial amounts, especially at lower design speed levels. This tendency points to the desirability that harmonizing design speed and operating speed is an important goal to be considered in new designs, redesigns, and rehabilitation strategies of rural roads.

Therefore, one of the major highway geometric design problems is the incompatibility in geometric and operational requirements which are caused by trying to fit together geometric components conveniently and economically rather than trying to satisfy operational requirements. Other inconsistencies are the result of upgrading a highway cross section without upgrading the alinement. Because cross section features can be more apparent than the alinement, there are instances where a wider cross section on an old alinement might convey a message to the driver and could lead to an inappropriate expectancy based on the visual aspects of the cross section. Geometric inconsistencies violate driver expectancy and, therefore, may degrade traffic operations and safety. They have higher workload requirements than drivers expect, and they often require abrupt changes in operating speed, path, or both. Such changes have been identified as surrogate measures for accident experience on rural highways.

To overcome this weakness in current practice, methods to improve highway alinement consistency and to generate a more uniform road characteristic have to be developed and especially regarded by highway design engineers in cases of new designs, major reconstructions, and for the redesigns of accident black spots as well as for rehabilitation- and restoration work.

Therefore, the following safety criteria should be regarded as important rules for reducing accident frequency and severity. We as highway design engineers need not only qualitative but also quantitative safety criteria for evaluating our roads in the future. Thus, the following three Safety Criteria should be applied in future highway geometric design, to achieve

- operating speed consistency (Safety Criterion I),
- design consistency (Safety Criterion II), and
- driving dynamic consistency (Safety Criterion III).

5.1 Safety Criteria I and II for Two-Lane Rural Roads

At the end of the 1980's two safety criteria for "Highway Geometric Design" of two-lane rural roads were developed for the U.S.A. by the author, which also are meanwhile recommended for Europe, for example to complete or replace the existing procedures in the German and the Swiss Guidelines/Standards.

They were introduced already into the new Greek Guidelines and were furthermore presented for Sweden, Japan, Hungary and Israel.

The development of the first two Safety Criteria is based:

- on the experience of Criterion I, that the driving behavior of motorists, expressed by the absolute difference of the 85th-percentile speeds between successive design elements, should fall into certain ranges, and
- on the experience of Criterion II, that considering individual design elements solely the absolute difference between the observed 85th-percentile speed and the desgin speed should also correspond to certain ranges, see Table 3.

The 85th-percentile speed is defined as that speed, which 85 % of passenger cars do not exceed under free flow conditions on clean, wet road surfaces.

Briefly concluded, these two criteria presented in Table 3 express the need to alleviate the accident risk and severity at curved sites and the corresponding transitions. In this connection it was found, that the most successful parameter in explaining much of the variability in 85th-percentile speeds (V85) and accident rates (AR) was the design parameter "curvature change rate of the single circular curve with transition curves (K_E)". This parameter describes the design of a curve through the length-related course of the curvature, which appears to be one of the most important variables regarding the operating speed- and accident situation. The formula for K_E is also presented in Table 3. Furthermore, this new design parameter includes the influence of the transition curves (in front and behind of the circular curve) and it regards the overall length as well as the central angle of the curved sites.

The ranges for the assessment of good design-, fair design-, and poor design levels for the design parameter "K_E" and the corresponding speed differences in Table 3 are based on accident research in the U.S.A. and Germany. For example, research carried out demonstrated the following:

- For all lane widths combined,

  (a) gentle curvilinear horizontal alinements consisting of tangents or transition curves, combined with curves up to $K_E \leq 180$ gon/km experienced the lowest average accident risk; classified here as "good design",

  (b) the accident rate on sections with a change in K_E-values between 180 gon/km and 360 gon/km was at least twice as high as that on sections with a change in K_E-values up to 180 gon/km, classified here as "fair design",

  (c) the accident rate on sections with a change in K_E-values between 360 gon/km and 540 gon/km was about four times higher as that on sections with a change in K_E-values up to 180 gon/km; classified here as "poor design".

The listed changes in the 85th-percentile speeds of Safety Criterion I for good, fair and poor design in Table 3 correspond on the average to the determined changes in the K_E-values between successive design elements for most of the investigated countries.

While Safety Criterion I deals with the 85th-percentile speed transition between successive design elements (for example: tangent to curve or curve to curve), Safety Criterion II is solely related to the circular curve itself and the tuning of the selected design speed (V_d) with the actually observed operating speed, expressed again by the 85th-percentile speed (V_{85i}). The corresponding ranges for harmonizing design- and operating speed are also presented for the different design levels of Safety Criterion II in Table 3.

For determining the 85th-percentile speeds (V_{85}) with regard to the curvature change rate of the single circular curve with transition curves (K_E), the so far known and the newest operating speed backgrounds are compiled in Figure 7 for various countries. By knowing the K_E-values of curved roadway sections and/or independent tangents ($K_E = 0$, compare [18]) the 85th-percentile speeds can be determined from Figure 7 for the respective country under study, and the existing or planned horizontal alinements can be characterized according to the ranges of Safety Criteria I and II in Table 3, based on good, fair, and poor design levels.

Operating speed backgrounds (like those in Figure 7) should be part of every modern highway design guideline, when striving for a good curvilinear alinement and for a more consistent and safer road characteristic. In this way "operating speed consistency" (Safety Criterion I) and "design consistency" (Safety Criterion II) can be achieved for the first time according to Table 3.

For those countries, where operating speed backgrounds do not exist so far, the following recommendations can be given, based on the experiences gained when establishing the relationships presented through the curves 1, 2, 3 and 5 in Figure 7.

In order to ensure that the speeds measured represented the free speeds desired by the driver under a set of roadway conditions and were not affected by other traffic on the road, only the speeds of isolated Passenger Cars with a minimum time gap of about 6 seconds were measured. Speed measurements were made during daytime hours on weekdays under dry pavement conditions. Passenger Cars heading a platoon of vehicles should not be regarded.

The basic method used for speed data collection involved the measurement of the time required for a vehicle to traverse a measured course laid out in the center of a curve. Speed measurements were also taken on preceding and succeeding tangents to the curved site. Length of the course was 50 m. The method used for measuring time over the measured distance involved use of transverse pavement markings that were placed at each end of the course and an observer who started and stopped an electronic stop watch as a vehicle passed the markings. The observer was placed at least 5 m from the pavement edge of the road to ensure that his presence would not influence the speeds of passing vehicles, but not too far away so as to minimize the cosine effect.

By applying this procedure, satisfactory speed data were obtained for both directions of travel. Because of money, time, and personnel constraints about 50 to 75 passsenger cars under free-flow conditions were sampled at each site for both directions of traffic. Speed data were then used to obtain the operating speed, expressed herein by the 85th-percentile speed - that speed below which 85 percent of the vehicles travel.

Normally about 100 curved sites with varying K_E-values between 0 and 500 gon/km should be sufficient to establish the operating speed background of the respective country under study.

The effect of wet pavements on 85th-percentile speeds of passenger cars were also examined. Ample evidence exists to indicate that wet pavement does not have a great effect on operating speed, and that drivers will not adjust their speeds sufficiently to accommodate inadequate wet pavement on curves in particular. Furthermore, results of the statistical analyses indicate that the relationship of the operating speed for dry pavement conditions (Figure 7) is also valid for wet pavement conditions so long as visibility is not affected appreciably by heavy rain. It is obvious that drivers do not seem to recognize the fact that because of the lower coefficients of friction on wet pavements as compared with dry, wet pavements could lead to critical driving maneuvers or even accidents.

When evaluating new designs, redesigns or existing roadways according to the ranges of Safety Criteria I and II in Table 3 it can be expected for

Case 1 (Good Design)

For those road sections, consistency in horizontal alinement exists between successive design elements, and the horizontal alinement does not create inconsistencies in vehicle operating speeds. No adaptions or corrections are necessary.

Case 2 (Fair Design)

These road sections may represent at least minor inconsistencies in geometric design between successive design elements. Normally, they would warrant traffic warning devices, but no redesigns.

Superelevation rates and stopping sight distances should be related to V85 to ensure that side friction assumed will accomodate to side friction demand.

Case 3 (Poor Design)

These road sections reveal strong inconsistencies in horizontal geometric design between successive design elements combined with those breaks in the speed profile that may lead to critical accident frequencies and -severities, and thereby to an uneconomic and unsafe operation. Therefore, normally redesigns are recommended.

5.2 Safety Criteria I and II for Mulitple Lane Rural Roads and Suburban Roads

The previous results are related to two-lane rural roads. For multiple lane rural roads, (like Interstates or Autobahnen) no statistically sound results are known for the relationship between 85th-percentile speed and road characteristics expressed by the design parameter "K_E", because of the normally very generous alinements of these roads. The few existing studies indicate, if at all, a very low decrease of the 85th-percentile speed with increasing K_E values.

Therefore, in general, Safety Crition I does not become relevant for "Multiple Lane" rural highways. For covering the safety aspects of Safety Criterion II, it is proposed in [17] to estimate the 85th-percentile speed (V_{85}) in the following way (for example for establishing superelevation rates and stopping sight distances):

$$V_{85} = V_d + 10 \text{ km/h}, \qquad V_d \geq 100 \text{ km/h} \tag{7}$$

$$V_{85} = V_d + 20 \text{ km/h}, \qquad V_d < 100 \text{ km/h} \tag{8}$$

where V_d is the design speed [km/h].

For "Suburban Roads" - this category group encompasses non built-up roads in the periphery and inside built-up areas (arterials and main collectors) - new investigations revealed again no statistically sound relationship between 85th-percentile speed and road characteristics (K_E). This is predominantly caused by the fact, that on these roads a considerably lower speed level exists depending on imposed speed limits and other traffic regulatory measures as well as on different structural and municipal design features. That means examining Safety Criterion I on these roads does not make sense for this road category. However, the studies also revealed that on those roads the 85th-percentile speed level is normally higher than the posted speed limit (V_{perm}). Therefore, it is recommended for reasons of traffic safety to regard Safety Criterion II for design purposes (i.e. relating superelevation rates, stopping sight distances) according to the following assumptions [17]:

$V_{85} = V_{perm} + 20$ km/h (for example primary arterials) (9)
$V_{85} = V_{perm} + 10$ km/h (for example secondary arterials) (10)
$V_{85} = V_{perm}$ (for example main colletor roads) (11),

where V_{perm} is the posted speed limit.

5.3 Driving Dynamic Safety Criterion III for Curve Design

It remains the development of a Safety Criterion III, which is able to evaluate the driving dynamic aspects when cornering. That means, Safety Criterion III is again related, like Safety Criterion II to the individual design element, in the present case "the circular curve". Safety Criterion III compares side friction assumed for curve design (f_R) in the existing Guidelines with the actual side friction demand (f_{RA}), needed at curved sites [6, 7].

In this connection it was shown, that the side friction factors for curve design, assumed for the different design speeds, in the Geometric Design Guidelines of Germany [13] and of the U.S.A. [23] are often exceeded by those, demanded by the 85th-percentile speeds under real world conditions. These situations begin with K_E-values of about > 225 gon/km and correspond to radii of curve of about R < 280 m according to Figure 8 for Germany as well as for the U.S.A. Furthermore, it could be proved, that in the case of good desgin levels, side friction assumed (f_R) exceeds side friction demand (f_{RA}). In the case of poor design levels, side friction demand exceeds side friction assumed, compare Figure 8.

Again, based on the recommended differences of the K_E-values for "good", "fair" and "poor" design levels in Table 3, the corresonding differences between side-friction assumed (f_R) and side friction demand (f_{RA}) were established through Figure 8. As can be seen from these figures the limiting values for "good" and "poor" design levels are nearly the same for Germany and the U.S.A. It was decided, to use the German limiting values as permissible-, respectively non-permissible ranges for Safety Criterion III (providing adequate dynamic safety of driving through circular curves), as demonstrated in Table 4. The decision to select the German values is based on the fact that besides circular curves the influence of transition curves is here already additionally regarded. Safety Criterion III is applicable for two-lane and multiple lane rural as well as for suburban roads.

6. PROCEDURE FOR DETECTING SAFETY ERRORS

An individual examination of roadway sections, based on the three Safety Criteria according to Table 5 is recommended, when evaluating specific roadway sections. This is especially true, when the highway engineer has information available about the planned or the existing highway, the safety quality (good or fair) to strive for and about local conditions and available funds. For example, the designer may be able to improve the alinement in cae of a failure of only one safety criterion in such a way, that the safety deficiency can be eliminated without affecting the other criteria and their design impacts.

In order to recognize safety errors for new designs or redesign already in the planning stages or necessary safety improvements for RRR-projects before implementation, modern planning tools have to be made available to the highway engineer. Complex data processing systems must be part of today's planning tools. Therefore, the following procedure is established in such a way, that it can be applied manually or using CAD [25].

6.1 Case Study: Old Alinement

The existing horizontal alinement of Figure 9a shows a two-lane rural State Route in South-West Germany in the plain of the River "Rhine". Accident analysis indicates a high accident frequency and severity at element 2 (R = 150 m). The longitudinal grades are less than 2 % and the AADT-values corresponded to 7200 vehicles per day in 1991. The lane width is 3.50 m. The "old" alinement should be improved, and the "new" alinement should represent the level "good design practice" for all three individual safety criteria.

With the exception of element 2 all the other curved roadway sections (elements 4 to 6) corresponded at least to a design speed of 90 km/h according to the German Guidelines for the Design of Roads [13]. Consequently it was decided to select 90 km/h as the design speed, in order to keep the reconstruction costs, as low as possible.

The design data of the old alinement, the design speed of V_d = 90 km/h, the lane width of LW = 3.50 m, the measured superelevation rates represent the input data for the Subprogram "Safety Computations", developed in [25]. In this subprogram the relationship between K_E-values and V_{85}-percentile speeds (in the present case for curve 4 of Figure 7) is stored, as well as the equations for calculating side friction assuemd (f_R) and side friction demand (f_{RA}), see Table 5. In this way Safety Criteria I to III according to Table 5 can be examined at once for "good", "fair" and "poor" design levels.

In Table 6 the output-data of the safety evaluation process are listed in numerical mode up to element 3. An analysis of the critical curve (element 2) indicates, that the absolute 85th-percentile speed differences between the elements 1 and 2 as well as between the elements 2 and 3 exceed 20 km/h and reveal "poor design" according to the ranges of Criterion I in

Table 5. The same is true for Criterion II regarding the absolute difference between 85th-percentile speed and design speed and for the driving dynamic Criterion III regarding the difference between side friction assumed (f_R) and side friction demand (f_{RA}) for the curve element 2. (Note, that the 85th-percentile values, computed here automatically by the subprogram based on the K_E-values, could also have been determined from Figure 7 (Curve 4) in case of a manual safety evaluation process. The same ist true for calculating side friction assumed (f_R) and side friction demand (f_{RA}) according to the formulas in Table 4.

A graphical presentation of the numerical results was developed currently with Table 6 and is presented in Figure 9a for use at the PC-screen or as printout. In this way the different design levels, based on the individual Safety Criteria I to III, can be recognized visually by using discriminating colors or symbols. For a better understanding it should be mentioned, that the graphical symbols for Criterion I are directed vertically to the road axis, while the symbols for Criterion II are arranged at the left side and those for Criterion III at the right side parallel to the axis.

By evaluating the graphical layout of Figure 9a it can be recognized at once, that the critical curve (element 2) corresponds to poor design practices regarding all investigated safety criteria. This result supports the previous statements about the serious accident situation at this curve site.

In addition it can be seen, that the curve with the radius of 400 m (element 4) can be only evaluated as "fair design" for Criterion I considering the transition between elements 3 and 4. Fair design practice could also be noticed for Criterion III in this curve. All the other road sections of the existing alinement in Figure 9a reveal "good design pratices" and don't need any changes with regard to future redesign tasks.

6.2 Case Study: Curvilinear Alinement

For safety reasons "good design levels" should always be strived for, if no other superior goals are of relevant importance. This is true for new designs of multilane as well as for two-lane rural or suburban roads. A procedure for achieving good design levels (also called "curvilinear alinement" or "relation design") is presented in Figure 9b. The results of the safety evaluation process show no safety errors or deficiencies, based on Criteria I to III according to this figure. All three criteria confirm "good design practices" for the curvilinear alinement along the whole observed two-lane rural roadway section. Thus, it can be expected, that the final alinement, presented in Figure 9b is a sound one.

6.3 Case Study: Safety Module for Road Networks

As an overall safety evaluation procedure the previously discussed three safety criteria shall be combined in an overall safety moduel [26]. Table 7 shows the classification system of the safety module, as based on the Criteria I to III for good, fair, and poor design levels. All three criteria are weighted equally. At least two of the three criteria have to be in agreement in the decision process in order to assess the design safety level. The developed procedure represents the current state of knowledge. Figure 10 schematically shows (using discriminating symbols or colours) the results of the overall safety module for a case study in Ehingen County in South-West Germany for good, fair, and poor designs. For developing those graphs the Geometric Information System "SPANS" was used [26, 27]. Normally the graphs are presented using discriminating colours, but because of the printing rules for this workshop black and white symbols had to be used. The sections without symbols in the figure were not subject for analysis.

Analyzing Figure 10 the discussed procedure indicates, that the process for evaluating networks by an overall safety module is possible and that this safety module does include the three discussed safety criteria in geometric highway design for the first time according to the classification system of Table 7.

To determine the degree of agreement between the developed safety module and actual accident rates on observed roadway sections, a three-year case study was conducted. The results are shown in Figure 11. As can be seen from this figure the circular symbol, which represents full agreement, and the triangular symbol, which represents a lower accident rate than the safety module would predict, predominate. Thus, it can be concluded, that in the majority of investigated road sections the actual accident rate agrees well with the developed safety module or the results are at least on the safe side. Only in the rare cases of the quadratic symbol the actual accident rate is higher than the predicted one.

Thus, the results of the overall safety module seem to be pointing in the right direction for evaluating roadway sections or networks with respect to design, redesign, rehabilitation and restoration strategies.

6.4 Conclusion

Three safety criteria for evaluating curved roadway sections including transition sections were analyzed in order to address these important target areas for reducing accident frequency and severity:

<u>Criterion I</u>	"Achieving Consistency in Horizontal Alinement",
<u>Criterion II</u>	"Harmonizing Design Speed and Operating Speed", and
<u>Criterion III</u>	"Providing Adequate Dynamic Safety of Driving".

The three safety criteria represent important tasks in modern highway design and redesign strategies for improving traffic safety.

A procedure for enabling the highway engineer to evaluate specific alinements of two-lane rural roads by applying the three discussed individual safety criteria was presented in this study.

Furthermore, the above safety criteria constituted the core of the overall safety module, proposed in this study for classifying road networks according to good, fair, or poor design. Criteria I to III can be applied manually or by using a Geographic Information System (GIS).

The results seem to be pointing in the right direction for evaluating individual roadway sections and overall networks with respect to design, redesign, rehabilitation, and restoration strategies.

7. CROSS SECTION DESIGN

As already mentioned several times cross section design has also a very important impact on traffic safety.

It is impossible to discuss in this workshop all relevant safety issues, which stand behind the individual cross sectional elements and the overall cross section design of multiple and two- or three-lane rural roads. For example, how to design vehicle space, moving space and safety space? All three influencing parameters with regard to speed lead finally to the determination of the lane width of a specific road. In this connection the importance of the paved shoulder as emergency lane should not be forgotten.

Typical Standard Cross Section for non built-up roads are presented in Figures 12 and 13, elaborated and modified according to the German Guidelines [20].

The letters a/b/c/d/e define the lane width in the following way

a) means a lane widths up to 3.75 m (inside lane), the other lanes of the multiple lane cross section are 3.50 m,

b) means a lane width of 3.50 m for multiple lane- and of 3.75 for two-lane cross sections,

c) means a lane width of 3.25 m for multiple lane- and of 3.50 m for two-lane cross sections.

Accordingly

d) means a lane width of 3.25 m and

e) means a lane width of 3.00 m for two-lane cross sections.

The numbers in the road designations mean the numbers of lanes of the cross section type.

m) means "Median",

s) means paved shoulder, for example as emergency lane,

SCS) means "Overall Width" of the Standard Cross Section.

Fundamentally, about cross section, road characteristic and safety can be argued: Road cross section, alinement and intersections are essential parts of road characteristics and influence together traffic safety. Therefore, they have to be tuned to each other and continuance of the same Standard Cross Section over longer roadway sections is very important for a consistent road characteristic.

The safety of traffic flow depends on numerous, partially unassessable influencing factors. Besides traffic volume and - composition the design of the cross section of the road is of significant importance. Since with decreasing lane width the moving and safety spaces decrease also, the risk with respect to opposing and passing vehicles increases, if the speed is not reduced accordingly.

Finally, it should not be forgotten, that for a safe and consistent road characteristic not only the horizontal alinement and the cross sections, but the vertical alinement is essential also, as well as the superimposition of these three components.

In conclusion allow me to say:

Highway Geometric Design is a science, like mathematics, physics, chemetry or biology etc.

But contrary to those sciences, we highway design engineers decide through our work about life and death, at least to an essential part.

Therefore, the people one day may look to us as "lifepreservers" or as persons, who did not care about life, families, grief combined with fatalities, and or serious injuries". Therefore, every one of us has to make the decision, what kind of highway engineer, he intends to beComes or to be.

General form for the equation of the Maximum Permissible Side Friction Fractor

$$f_{Rperm} = n \times 0.925 \times f_{Tperm} \quad (1)$$

RURAL ROADS

Flat Topography, Maximum Superelevation Rate e_{max} = 8(9)%

$$n = 45\ \%$$

$$f_{Rperm} = 0.45 \times 0.925 \times f_{Tperm} = 0.42 \times f_{Tperm} \quad (2a)$$

$$f_{Rperm} = 0.25 - 2.04 \times 10^{-3} \times V_d + 0.63 \times 10^{-5} \times (V_d)^2 \quad (2b)$$

Hilly and Mountainous Topography, Maximum Superelevation Rate e_{max} = 7 %

$$n = 40\ \%$$

$$f_{Rperm} = 0.40 \times 0.925 \times f_{Tperm} = 0.37 \times f_{Tperm} \quad (3a)$$

$$f_{Rperm} = 0.22 - 1.79 \times 10^{-3}\ V_d + 0.56 \times 10^{-5} \times (V_d)^2 \quad (3b)$$

Minimum Superelevation Rate e_{min} = 2.5 %

$$n = 10\ \%$$

$$f_{Rperm} = 0.10 \times 0.925\ f_{Tperm} \quad (4a)$$

$$f_{Rperm} = 0.05 - 0.45 \times 10^{-3}\ V_d + 0.14 \times 10^{-5} \times (V_d)^2 \quad (4b)$$

SUBURBAN ROADS

Maximum Superelevation Rate e_{max} = 6 %

$$n = 60\ \%$$

$$f_{Rperm} = 0.60 \times 0.925 \times f_{Tperm} = 0.56 \times f_{Tperm} \quad (5a)$$

$$f_{Rperm} = 0.33 - 2.72 \times 10^{-3}\ V_d + 0.85 \times 10^{-5} \times (V_d)^2 \quad (5b)$$

Minimum Superelevation Rate e_{min} = 2.5 %

$$n = 30\ \%$$

$$f_{Rperm} = 0.30 \times 0.925 \times f_{Tperm} = 0.28 \times f_{Tperm} \quad (6a)$$

$$f_{Rperm} = 0.16 - 1.35 \times 10^{-3} \times V_d + 0.42 \times 10^{-5} \times (V_d)^2 \quad (6b)$$

Table 1: Recommended Equations for the Relationships between Maximum Permissible Side Friction Factors and Design Speed for Different Road Category Groups, Topography Classes as well as Maximum and Minimum Superelevation Rates

Design Speed km/h		40	50	60	70	80	90	100	110	120
Category Groups "Rural Roads (RR)" and "Suburban Roads (SR)"										
f_{Tperm}		0.420	0.385	0.353	0.324	0.299	0.276	0.256	0.239	0.225
Category Group "RR" (Flat Topography, e_{max})										
f_{Rperm}	n=0.45 e_{max}=8(9)%	-	0.160	0.147	0.135	0.124	0.115	0.107	0.100	0.094
R_{min} [m]		- -	85 (80)	125 (120)	180 (170)	250 (235)	330 (310)	425 (400)	530 (500)	650 (620)
Category Group "RR" (Hilly and Mountainous Topography, e_{max})										
f_{Rperm}	n=0.40 e_{max}=7%	-	0.143	0.131	0.120	0.110	0.102	0.095	0.089	0.083
R_{min} [m]		-	95	140	200	280	370	480	600	740
Category Group "RR" (All Topography Classes, e_{min})										
f_{Rperm}	n=0.10 e_{min}=2.5%	-	0.036	0.033	0.030	0.028	0.026	0.024	0.022	0.021
R_{min} [m]		-	325	490	700	960	1250	1600	2000	2500
Category Group "SR" (e_{max}, e_{min})										
f_{Rperm}	n=0.60 e_{max}=6%	0.233	0.214	0.196	0.180	0.166	0.153	-	-	-
R_{min} [m]		45	70	110	160	225	300	-	-	-
f_{Rperm}	n=0.30 e_{min}=2.5%	0.117	0.107	0.098	0.090	0.083	0.077	-	-	-
R_{min} [m]		90	150	230	335	470	630	-	-	-

Legend

RR = Rural Roads; SR = Suburban Roads

Driving Dynamic Formula for Curve Design

$$R = \frac{V_d^2}{127 \times (f_R + e)} \quad (7)$$

R : radius of curve [m]
f_R: side friction factor [-]
e : superelevation rate [%/100]
V_d : design speed [km/h]

Table 2: Maximum Permissible Tangential and Side Friction Factors and Recommended Minimum Radii of Curve with Regard to Design Speed, Road Category Group, Topography as well as Maximum and Minimum Superelvation Rates.

SAFETY CRITERION I (Operating Speed Consistency)

CASE 1: Good Design Level

Permissible Differences:

$|K_{Ei} - K_{Ei+1}| \leq 180$ gon/km

$|V_{85i} - V_{85i+1}| \leq 10$ km/h

CASE 2: Fair Design Level

Tolerated Differences:

$180 \text{ gon/km} < |K_{Ei} - K_{Ei+1}| \leq 360$ gon/km

$10 \text{ km/h} < |V_{85i} - V_{85i+1} \leq 20$ km/h

CASE 3: Poor Design Level

Non-Permissible Differences:

$|K_{Ei} - K_{Ei+1}| > 360$ gon/km

$|V_{85i} - V_{85i+1}| > 20$ km/h

SAFETY CRITERION II (Design Consistency)

CASE 1: Good Design Level

$|V_{85i} - V_d| \leq 10$ km/h

CASE 2: Fair Design Level

$10 \text{ km/h} < |V_{85i} - V_d| \leq 20$ km/h

CASE 3: Poor Design Level

$|V_{85i} - V_d| > 20$ km/h

$$K_E = \frac{\left(\frac{L_{cr}}{R} + \frac{L_{cl1}}{2R} + \frac{L_{cl2}}{2R}\right) \cdot 63700}{L}$$

where L = $L_{cr} + L_{cl1} + L_{cl2}$ = Length of curve [km]

K_E = Curvature Change Rate of the Single Circular Curve with Transition Curves [gon/km]

L_{cr} = Length of circular curve [m]

R = Radius of circular curve [m]

L_{cl1}, L_{cl2} = Lenght of clothoids in front and behind [m]

V_{85i} = 85th-percentile speed of design element "i" [km/h]

V_d = Design speed [km/h]

Table 3: Ranges of the Safety Criteria I and II for Good, Fair and Poor Design Levels for Two-Lane Rural Highways.

SAFETY CRITERION III

Case 1: Good Design Level

$K_E \le 180$ gon/km

Permissible Differences:

$+0.01 \le f_R - f_{RA}$ (Germany)

$+0.015 \le f_R - f_{RA}$ (U.S.A.)

Case 2: Fair Design Level

$180 < K_E \le 360$ gon/km

Tolerated Differences:

$-0.04 \le f_R - f_{RA} < +0.01$ (Germany)

$-0.03 \le f_R - f_{RA} < +0.015$ (U.S.A.)

Case 3: Poor Design Level

$K_E > 360$ gon/km

Non-Permissible Differences:

$f_R - f_{RA} < -0.04$ (Germany)

$f_R - f_{RA} < -0.03$ (U.S.A.)

Legend: See Table 3 and Figure 8, as well as the following Equations:

$$f_R = \frac{V_d^2}{127 \times R} - e \; [-]$$

$$f_{RA} = \frac{V_{85}^2}{127 \times R} - e \; [-]$$

e = superelevation rate [%/100]

Table 4: Ranges of the Safety Criterion III for Good, Fair and Poor Design Levels for Two-Lane Rural Roads.

Safety Criterion	Good	Fair	Poor
	Design Levels		
I	Permissible: $\lvert V_{85i} - V_{85i+1} \rvert \leq 10$ km/h	Tolerated: 10 km/h $< \lvert V_{85i} - V_{85i+1} \rvert \leq 20$ km/h	Non-Permissible: 20 km/h $< \lvert V_{85i} - V_{85i+1} \rvert$
II	$\lvert V_{85i} - V_d \rvert \leq 10$ km/h	10 km/h $< \lvert V_{85i} - V_d \rvert \leq 20$ km/h	20 km/h $< \lvert V_{85i} - V_d \rvert$
III	$+ 0.01 \leq f_R - f_{RA}$	$- 0.04 \leq f_R - f_{RA} < + 0.01$	$f_R - f_{RA} < - 0.04$

V_{85i} = 85th Percentile Speed; V_d = Design Speed
f_R = Side Friction "Assumed"; f_{RA} = Side Friction "Demand"

Table 5: Range of the Safety Criteria I to III for Good, Fair, and Poor Design Levels.

```
AXIS : 1

ELEM. : 1      STATION          CLOTHOIDS         K_E                  SUPER-
 RADIUS    FROM      TO      BEFORE   BEHIND              V85    ELEVATION
   0       0.00    1190.42    0.00     0.00      0.00    99.70      2.5

   CRIT. II  : |V85_1 - V_d| = 9.70   => GOOD DESIGN
--------------------------------------------------------------------------------
Transition 1-2 for Crit. I : |V85_1 - V85_2| = 32.98 => POOR DESIGN
--------------------------------------------------------------------------------
ELEM. : 2      STATION          CLOTHOIDS         K_E                  SUPER-
 RADIUS    FROM      TO      BEFORE   BEHIND              V85    ELEVATION
  -150   1190.42  1390.00     0.00     0.00    424.67   67.32      7.0

   CRIT. II  : |V85_2 - V_d|      = 22.68  => POOR DESIGN
   CRIT. III :   f_R  - f_RA      = -0.09  => POOR DESIGN
--------------------------------------------------------------------------------
Transition 2-3 for Crit. I : |V85_2 - V85_3| = 32.98 => POOR DESIGN
--------------------------------------------------------------------------------
ELEM. : 3      STATION          CLOTHOIDS         K_E                  SUPER-
 RADIUS    FROM      TO      BEFORE   BEHIND              V85    ELEVATION
   0     1390.00  2373.79     0.00     0.00      0.00    99.70      2.5

   CRIT. II  : |V85_3 - V_d|    =   9.70   => GOOD DESIGN
--------------------------------------------------------------------------------
Transition 3-4 for Crit. I : |V85_3 - V85_4| = 15.95 => FAIR DESIGN
--------------------------------------------------------------------------------
```

Table 6: Example of the Numerical Output Data for the Safety Evaluation Process for Elements 1 to 3 (Old Alinement).

CLASSIFICATION	
by Criteria I to III	of the Safety Module
1	2
3 x good 2 x good/1 x fair 2 x good/1 x poor	Good Design
3 x fair 2 x fair/1 x good 2 x fair/1 x poor 1 x good/1 x fair/1 x poor	Fair Design
3 x poor 2 x poor/1 x good 2 x poor/1 x fair	Poor Design

Table 7: Classification of the Safety Module for Good-, Fair- and Poor Design Levels.

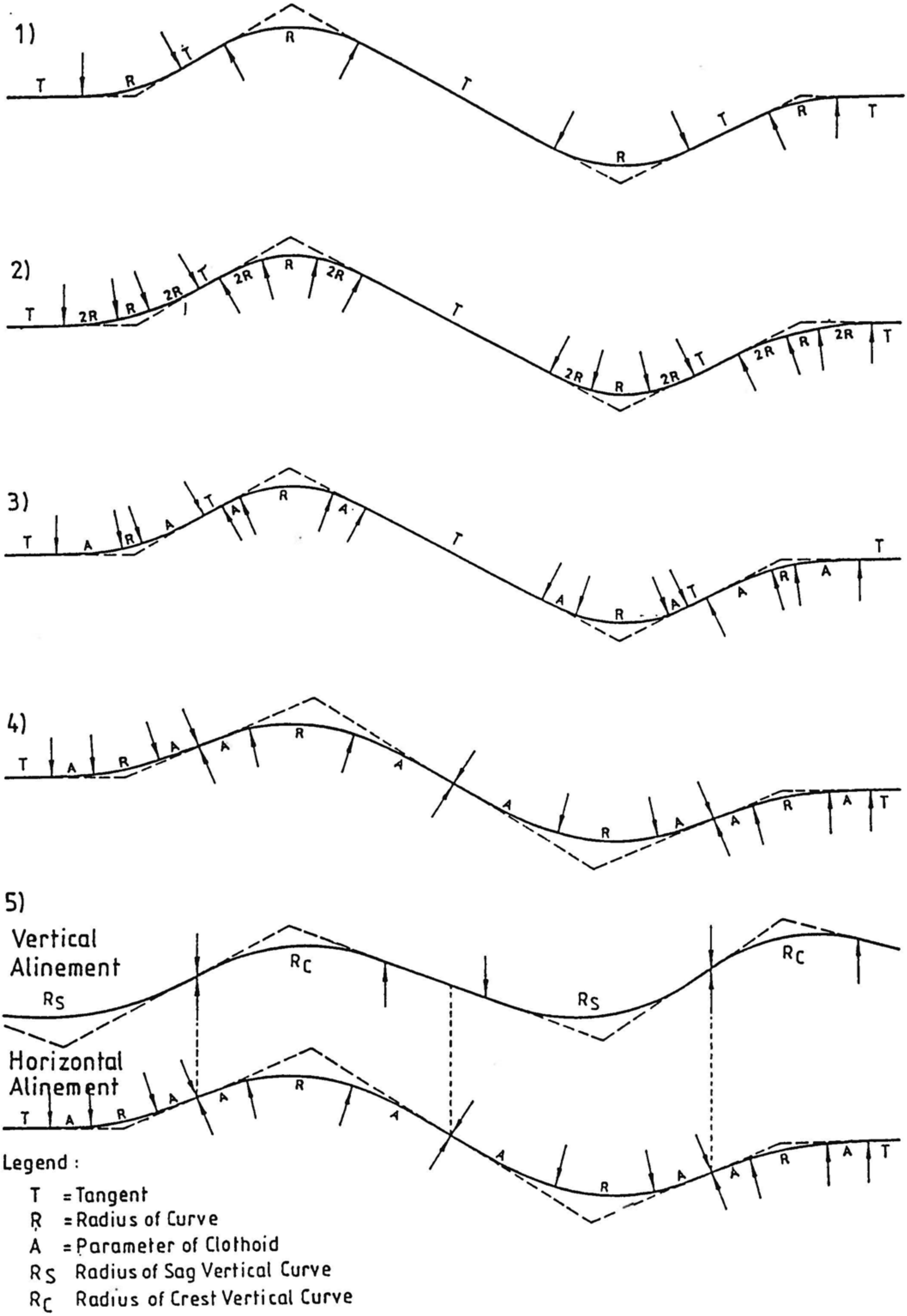


Figure1 : Development of Alinement Design

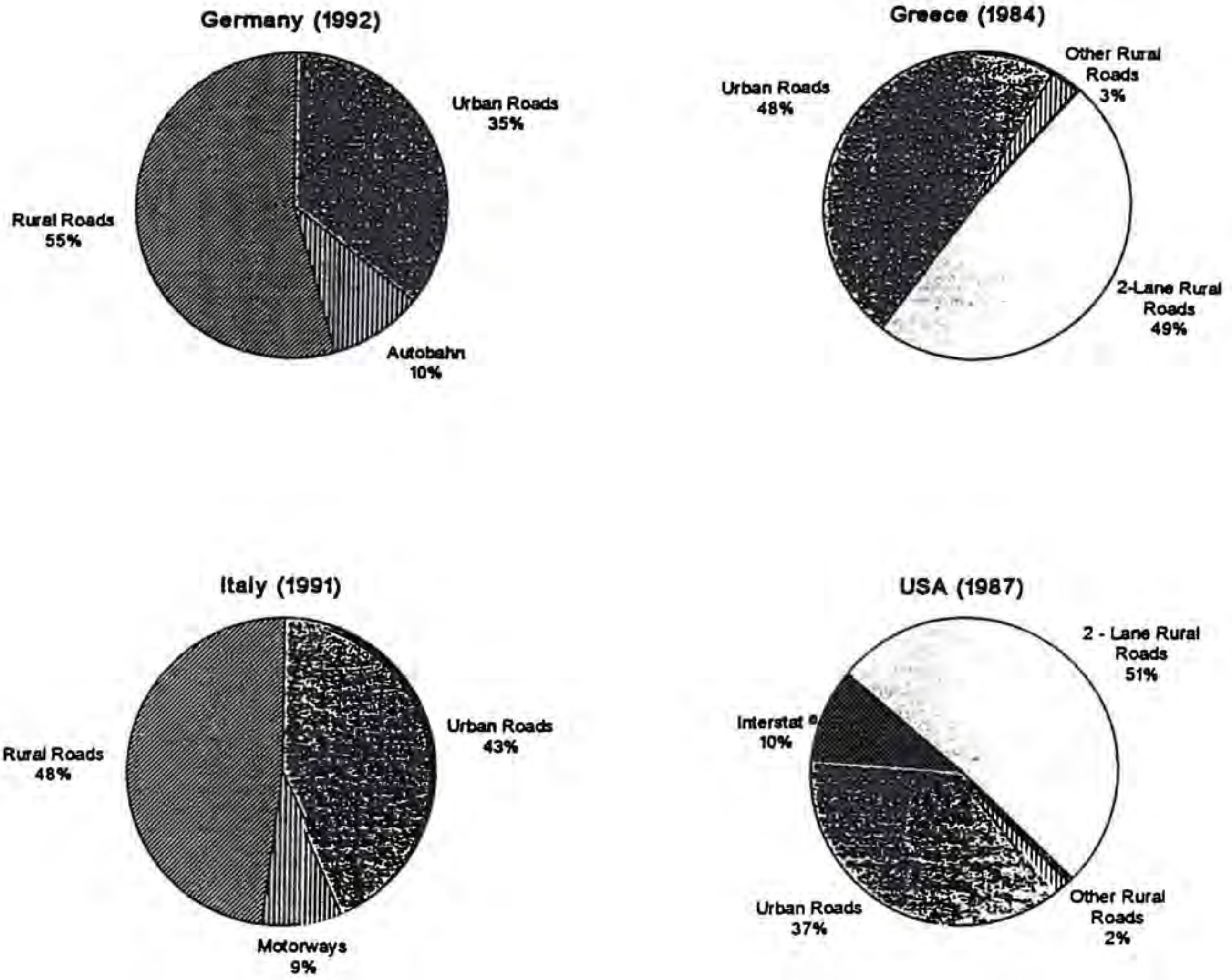


Figure 2 : Distribution of Fatalities for Different Road Categories in Selected Countries.

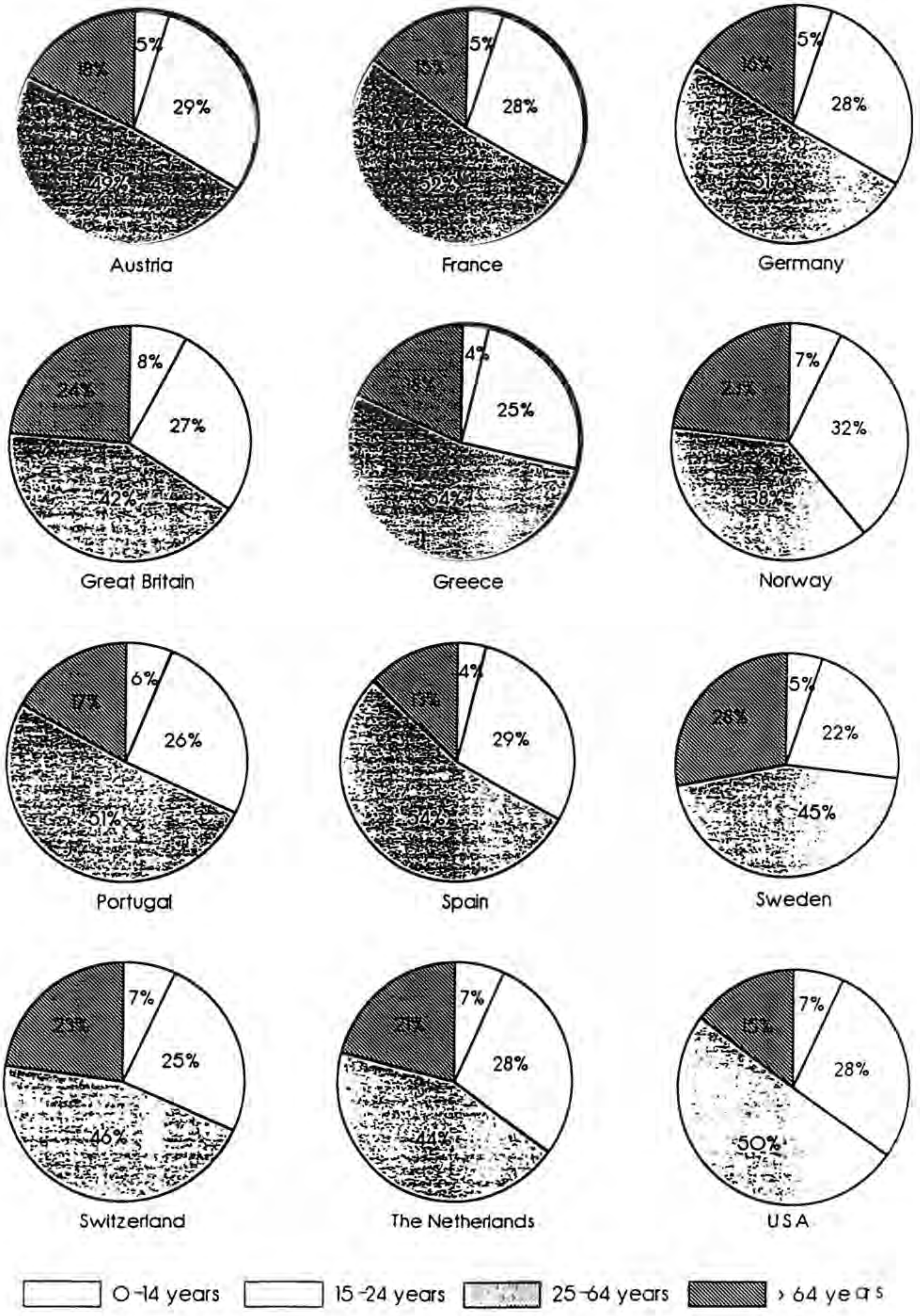


Figure 3 : Distribution of Fatalities by Age Groups for Selected Countries (1991).

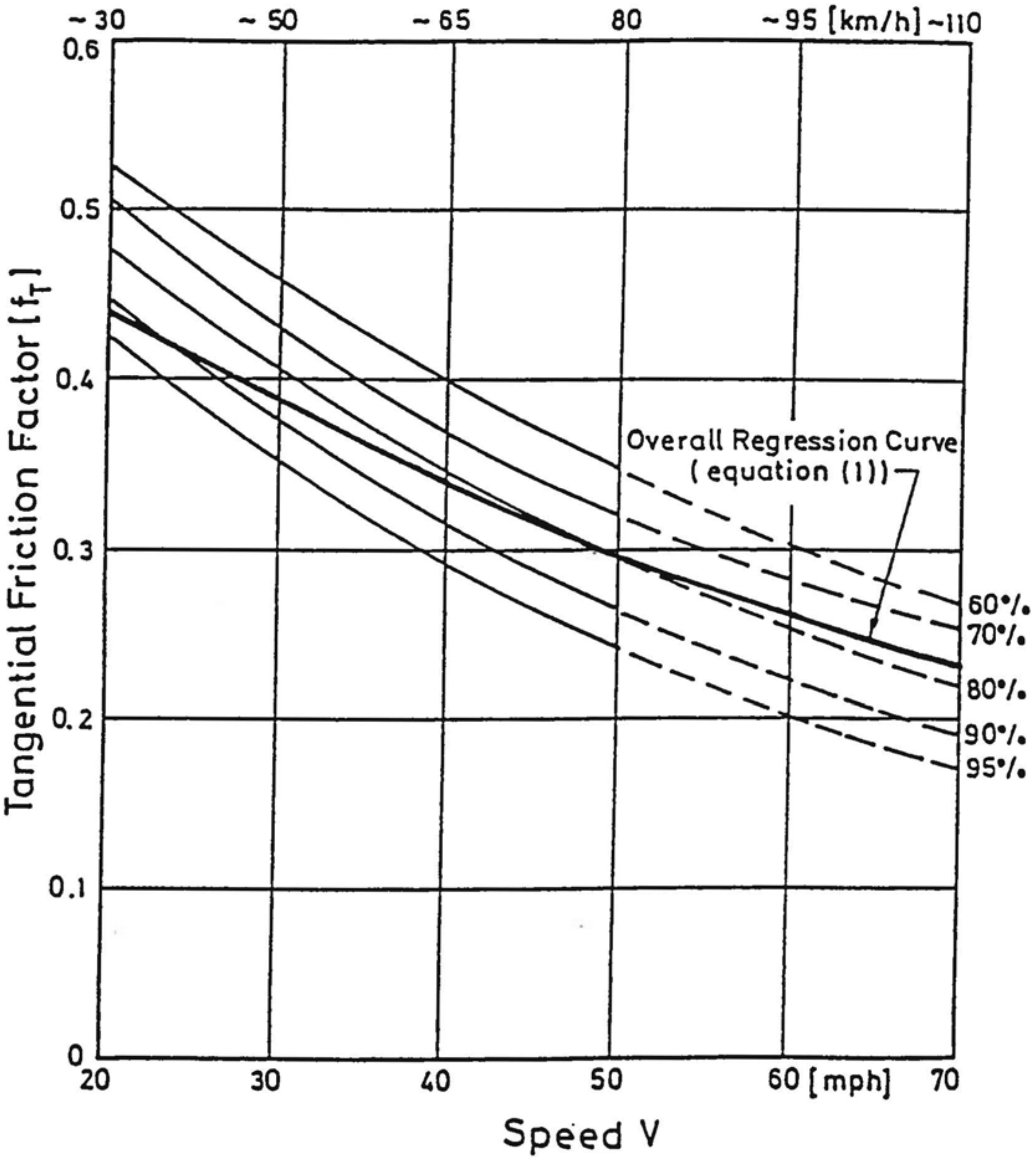
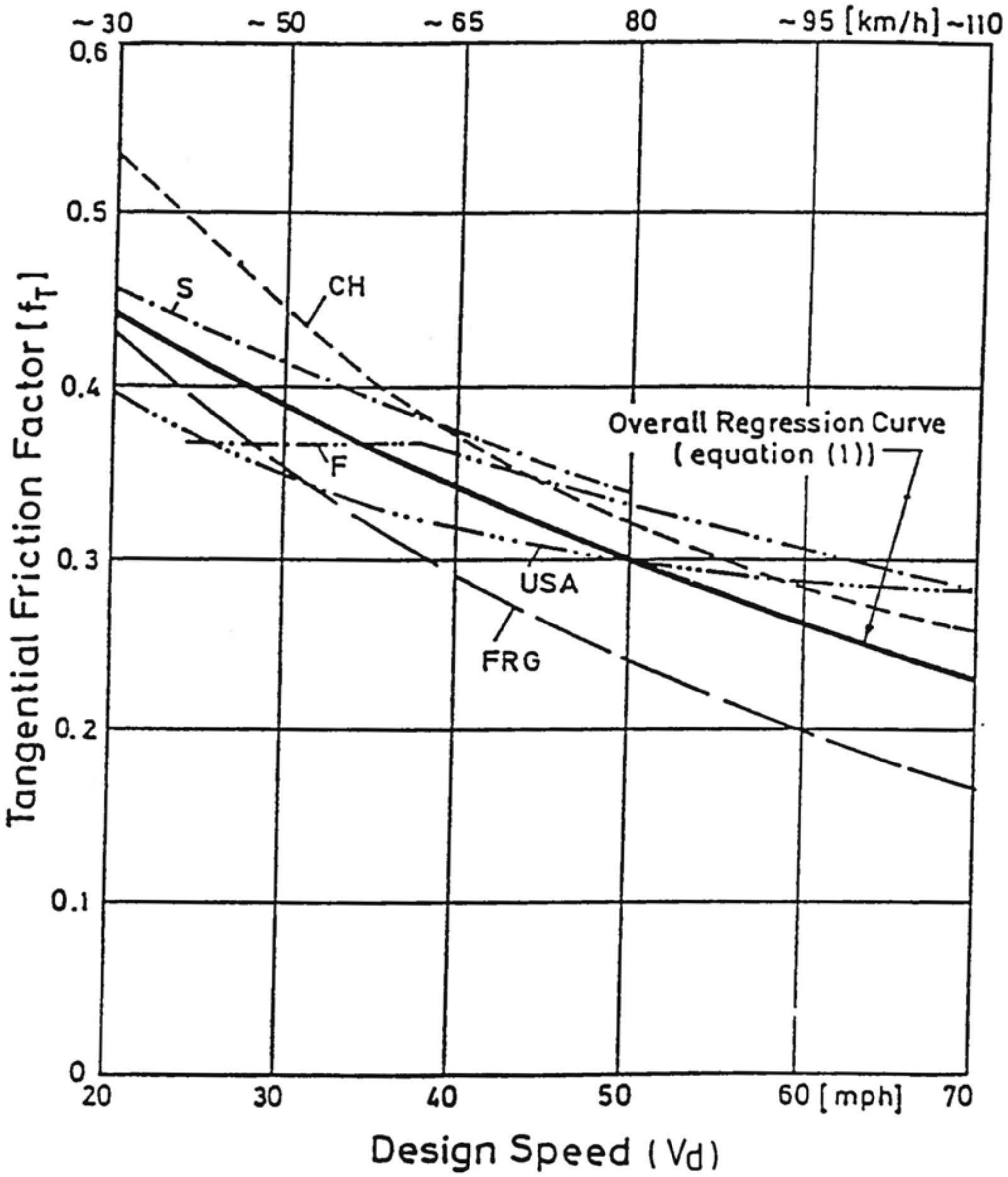


Figure 4: Percentile Distribution Curves for the Relationship between Tangential Friction Factor and Speed for 600 Wet Pavements in the Federal Republic of Germany



Overall Tangential Friction Regression Equation:

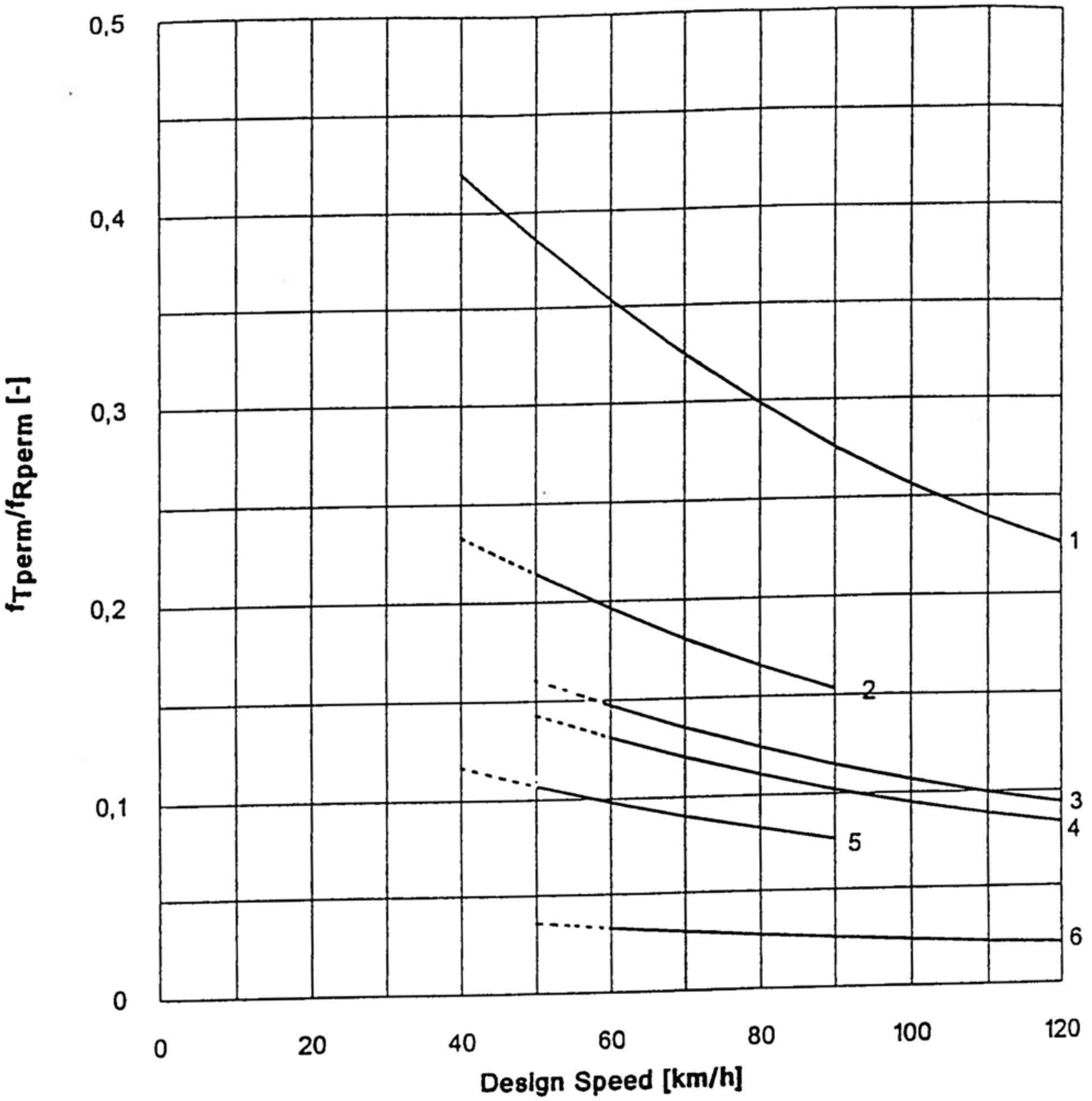
$$f_{Tperm} = 0.59 - 4.85 \cdot 10^{-3} \cdot V_d + 1.51 \cdot 10^{-5} \cdot (V_d)^2$$

$$R^2 = 0.731$$

where f_{Tperm}: maximum permissible tangential friction factor [-]

V_d : design speed [km/h]

Figure 5: Relationships between Maximum Permissible Tangential Friction Factor and Design Speed for Different Countries, along with the Overall Regression Curve [12].



Legend:

1 f_{Tperm} for "RR" and "SR"
2 f_{Rperm} for "SR" n=60 % e_{max} = 6%
3 f_{Rperm} for "RR" Flat Topog. n=45 % e_{max}=8%(9%)
4 f_{Rperm} for "RR" Hilly/Mount. Topog. n=40% e_{max} = 7%
5 f_{Rperm} for "SR" n=30% e_{min} = 2.5%
6 f_{Rperm} for "RR" All Topog. classes n = 10% e_{min} = 2.5%

f_T/f_{Rperm} = maximum permissible tangential/side friction factors

RR = Rural Roads

SR = Suburban Roads

n = utilization ratio of side friction

e_{max}/e_{min} = maximum/minimum superelevation rates

Figure 6: Graphical Presentation for the Relationships "Side Friction Factor vs. Design Speed", Compare also Tables 1 and 2.

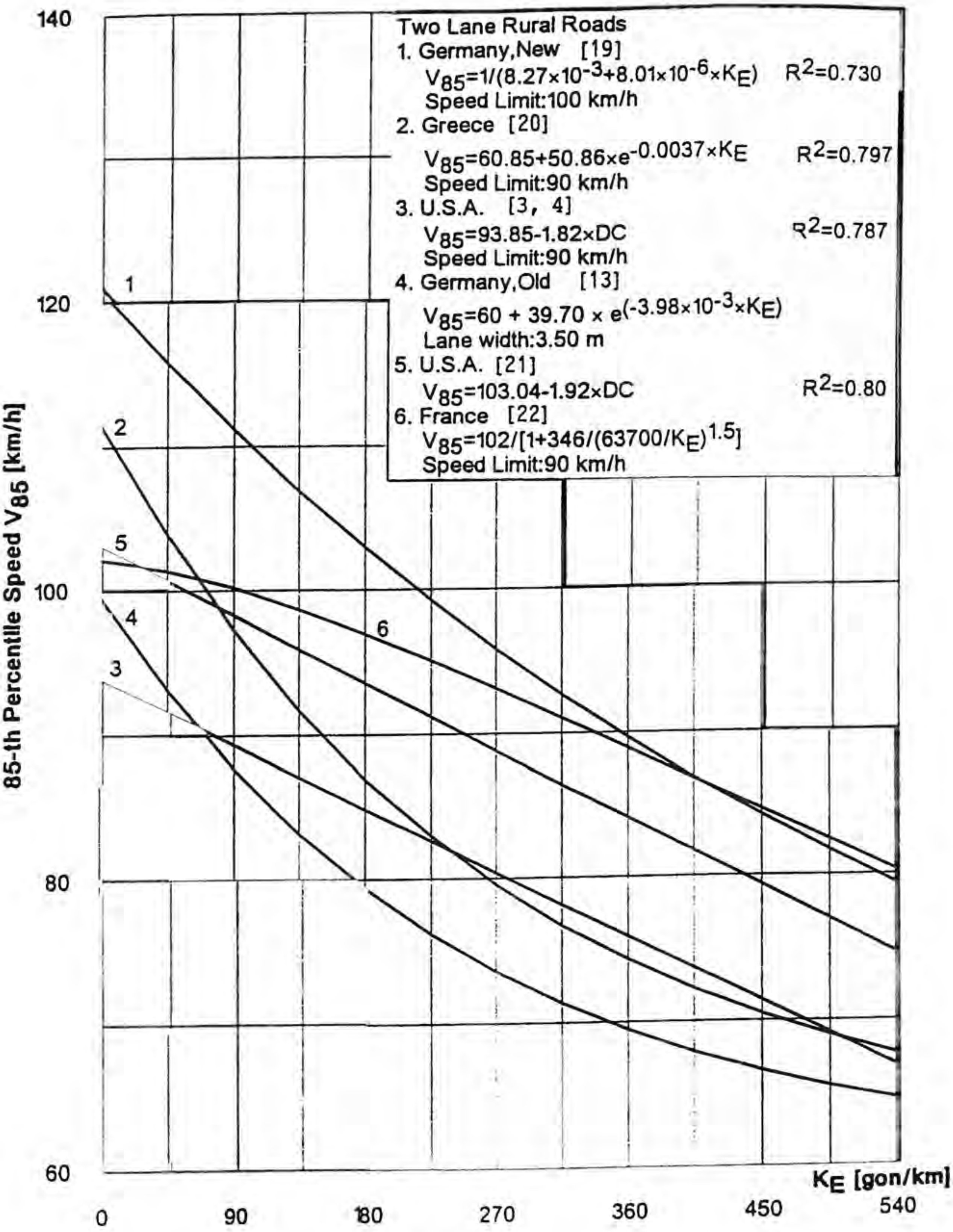
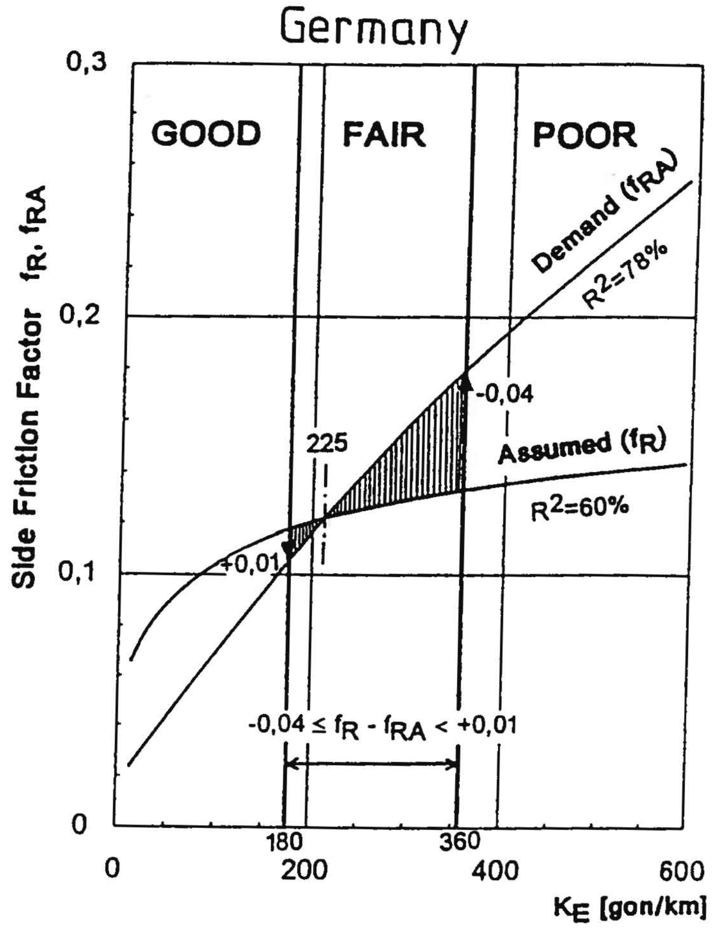


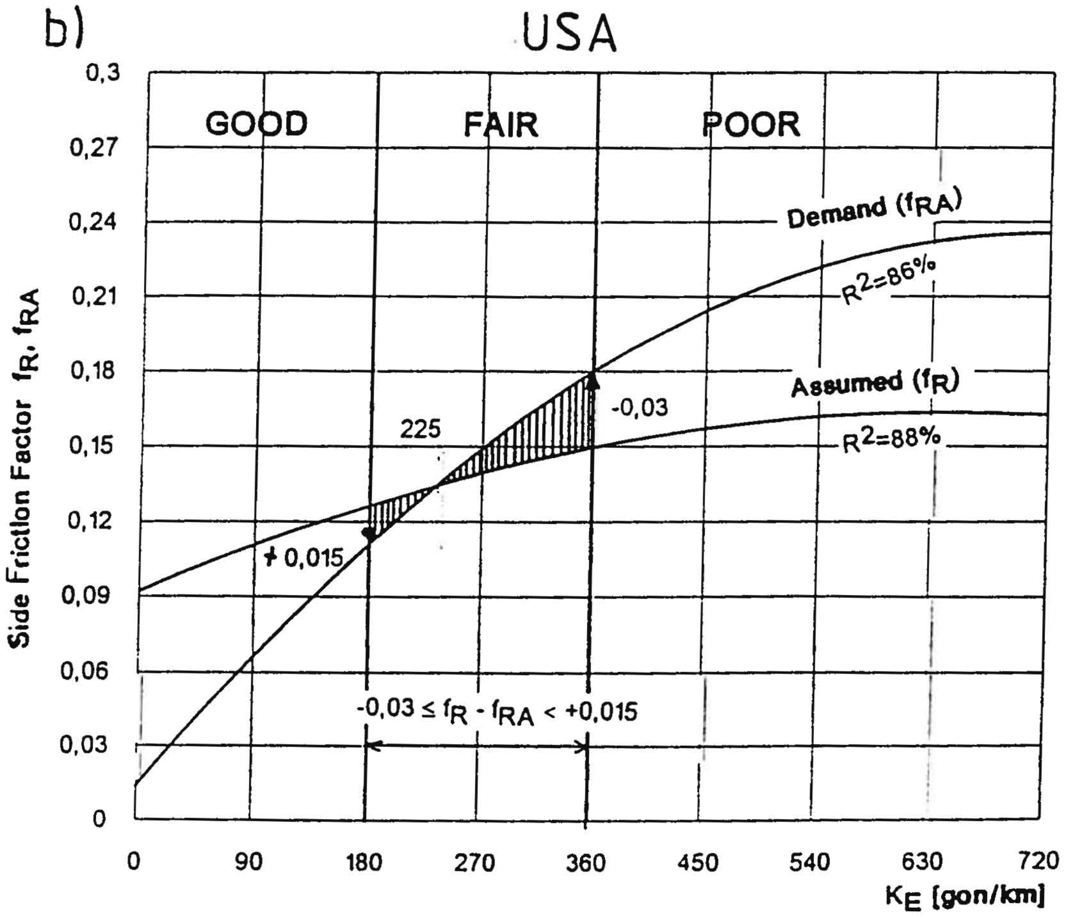
Figure 7 : Operating Speed Backgrounds for Different Countries and Two-Lane Rural Roads (The necessary conversions and different data bases effect the accuracy of this diagram marginally).

a)



Database:
657 Curved Sites [24]

b)



Database:
197 Curved
Sites [6,7]

Legend: See Table 3.

f_R = Side Friction Assumed [-]　　f_{RA} = Side Friction Demand [-]

Figure 8: Evaluation Backgrounds for Side Friction Assumed/Demand, Related to the Curvature Change Rate of the Single Curve for Germany and the U.S.A.

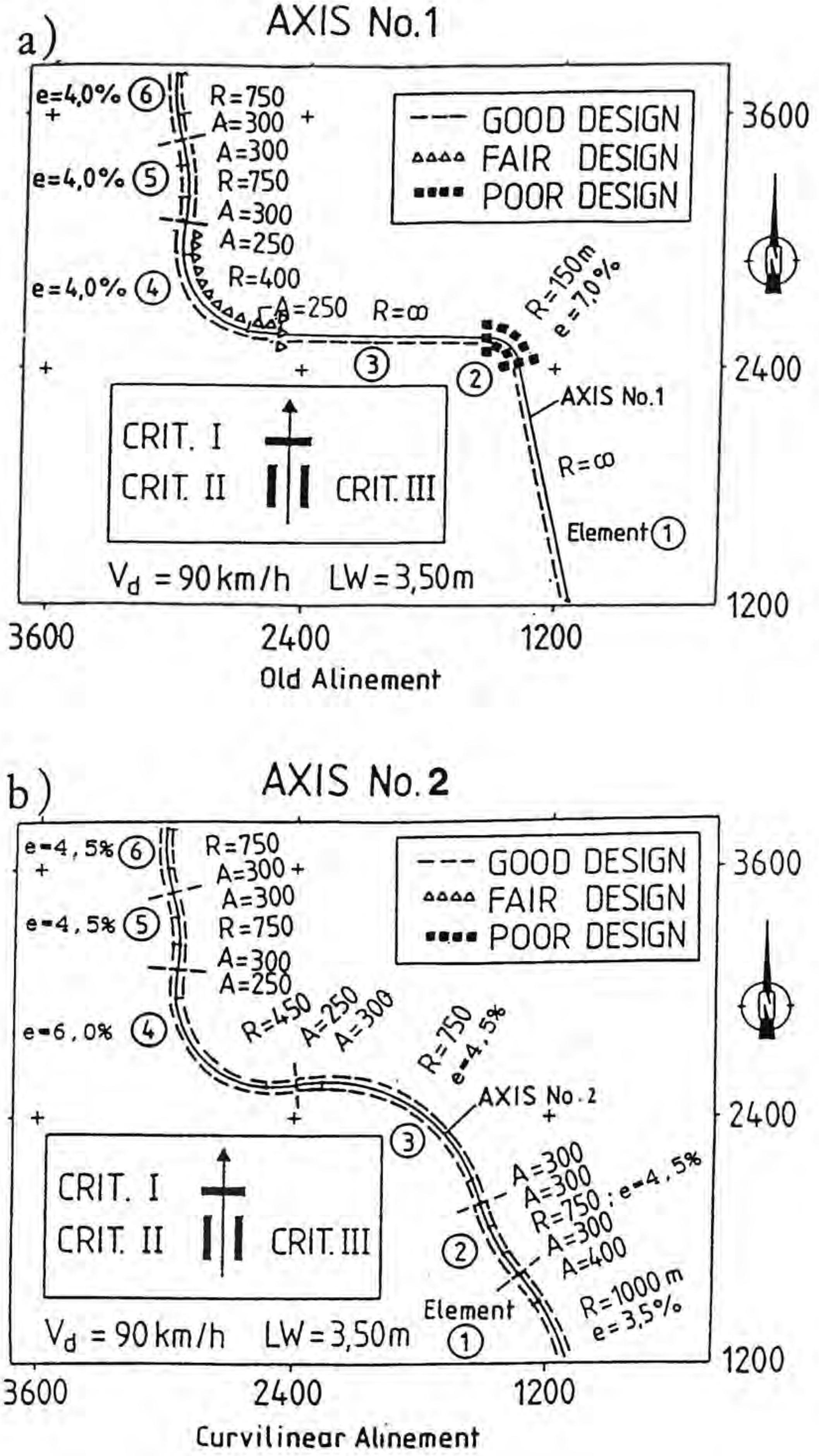


Figure 9 : Graphical Presentation of the Safety Evaluation Process

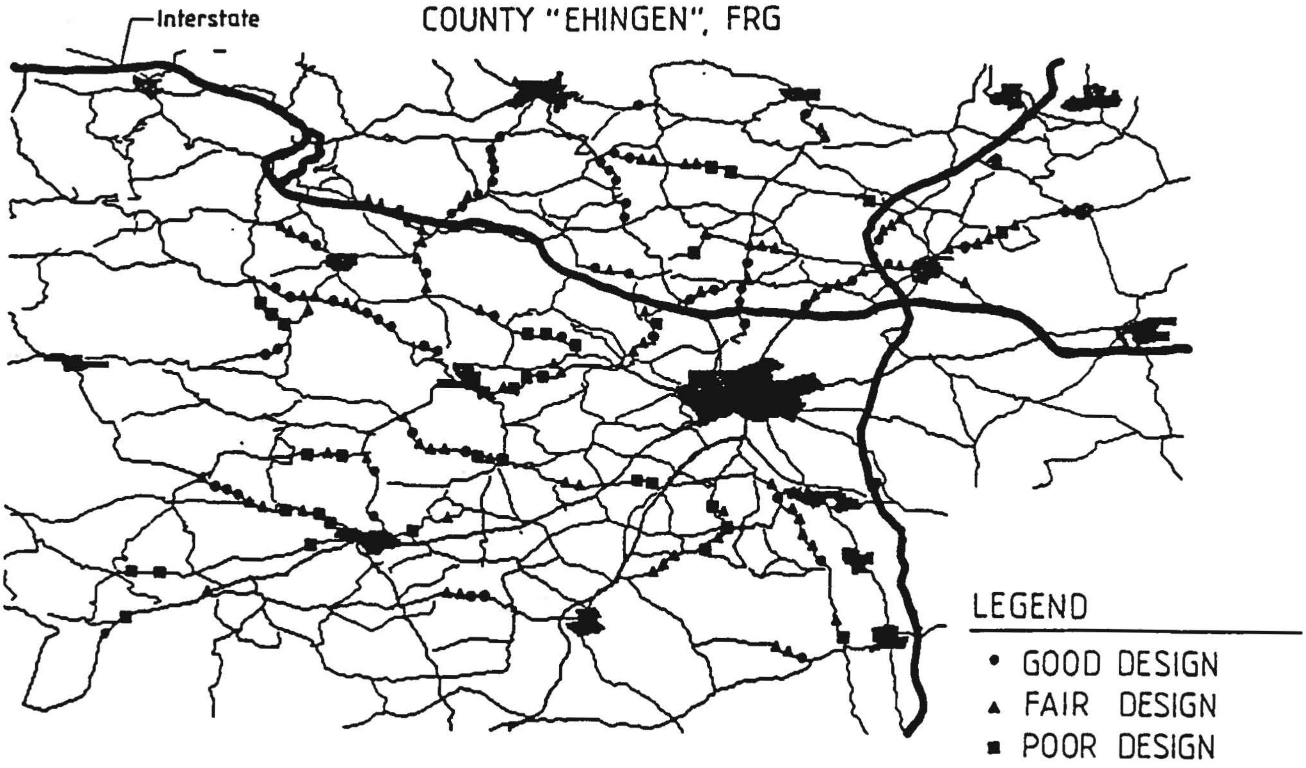


Figure 10: Results of the Overall Safety Module

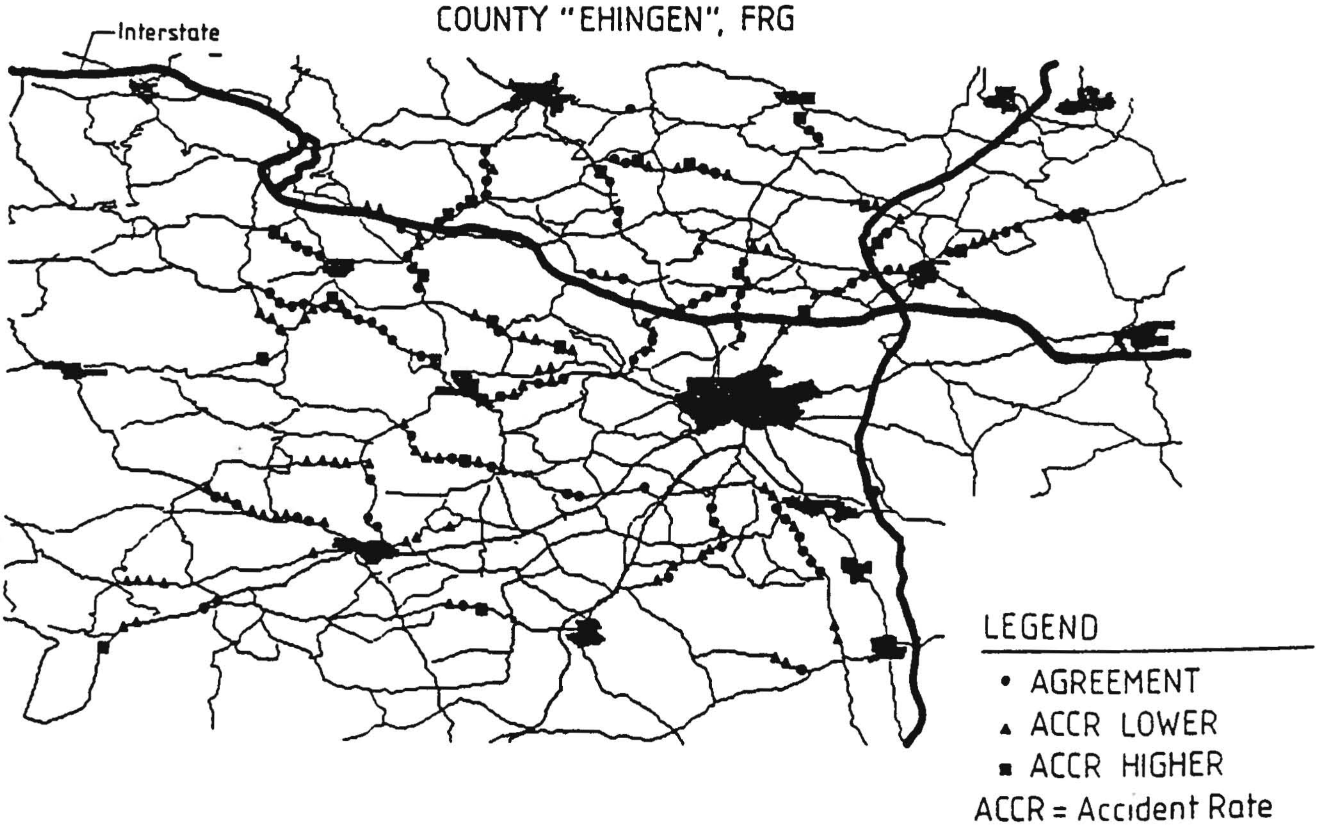
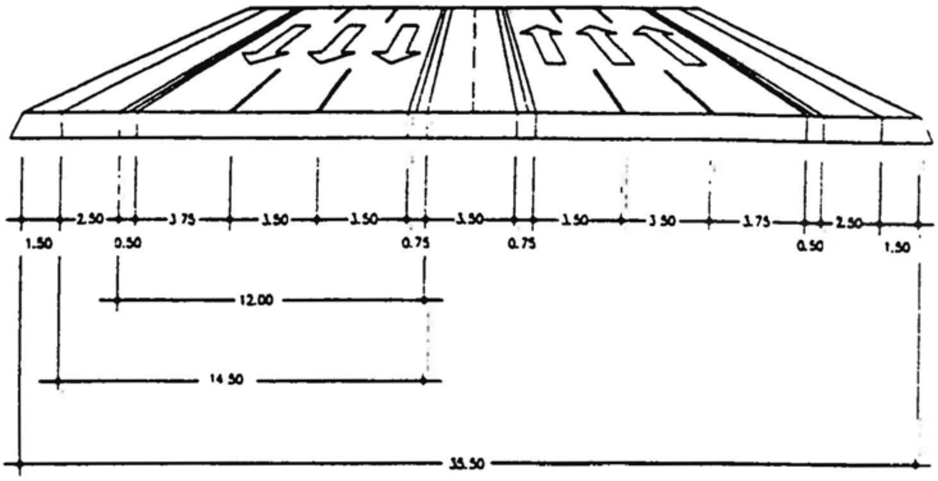
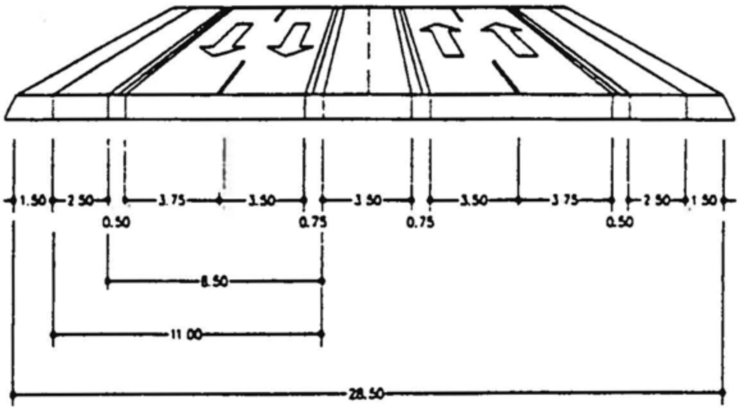


Figure 11: Level of Agreement between Safety Module and Actual Accident Rate

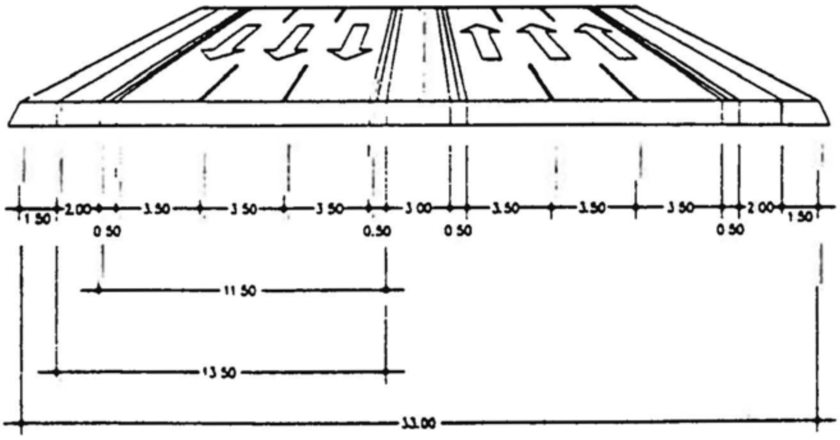
a 6ms
SCS = 35,50 m



a 4ms
SCS = 28,50 m



b 6ms
SCS = 33,00 m
(The cross Section
b 4ms, SCS = 26,00 m
can be built up
accordingly)



c 4ms
SCS = 24,00 m

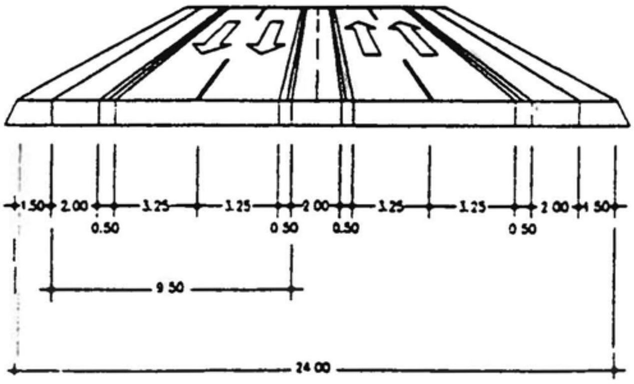
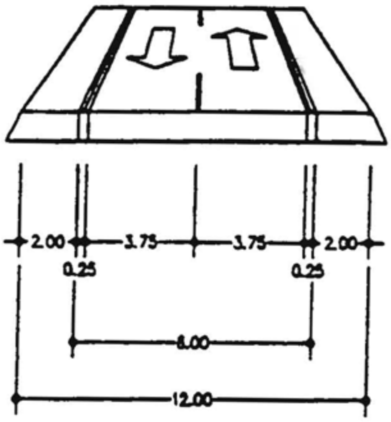
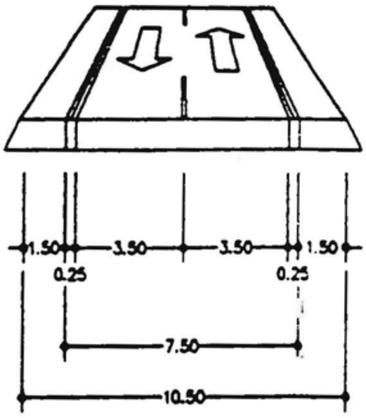


Figure 12: Multiple Lane Standard Cross Sections

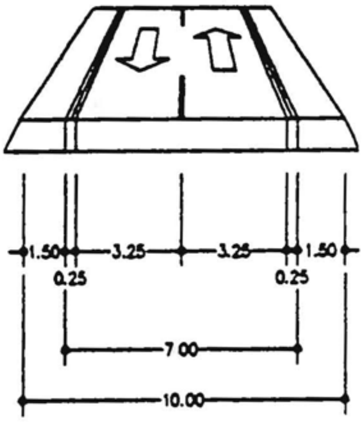
b2
SCS = 12,00 m



c2
SCS = 10,50 m



d2
SCS = 10,00 m



e2
SCS = 9,50 m

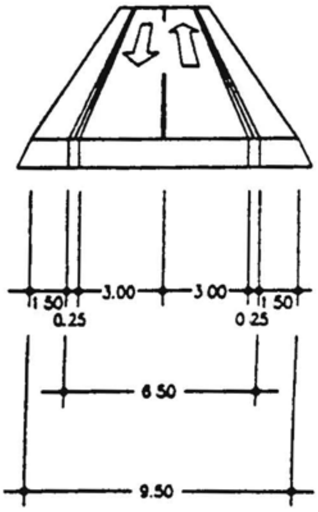


Figure 13 : Two-Lane Standard Cross Sections

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URBAN STREETS

By Kenneth Kjemtrup, The Danish Road Directorate

0. Introduction

The condition for attaining the greatest possible level of road safety on urban road networks is that road users behave in a manner that reduces the risk of accidents.

Road users' understanding of risks is culturally conditioned and is related to their respect and consideration for other people.

Depending on road users' understanding of risks, it is the road designer's job to design a road network that gives to the road user clear signals on the behaviour that promotes traffic safety.

Regardless of this, the designer should take care that the traffic picture is comprehensible and simple, in order to minimise the cognitive loading.

Due to differences in traffic culture it is not appropriate to offer unambiguous instructions on the correct design. This paper concentrates therefore on describing certain fundamental physical conditions for the development of good design.

Section 2, however, offers recommendations that are based on general European experience of designing for road safety.

1. Conditions for geometric design

In recognition of the fact that economic means are limited, and that it is therefore a question of using the means with the greatest benefit/cost ratio, the overall need for investment in the total road network should be reviewed. A plan should be drafted for where and how the flow of current and future traffic is to be maintained.

1.1 Traffic plan

A traffic plan should be drafted that covers the motorists' road network, the light road users' road network and the public transport system's road network. When establishing these road networks, consideration should be given to road safety, a sense of security, accessibility, passability, capacity, clearness, the environment and urban architecture.

Hard traffic should be separated from soft traffic to the extent possible and fast traffic should be separated from slow traffic. Where possible, the traffic system should therefore be designed on the principle of traffic differentiation.

However, it is not normally possible to do this in established urban areas, where a large part of the street network is used by both hard and soft road users. Thus, in practice, there will be a significant degree of coincidence between the networks of the different traffic systems.

The established streets in urban areas are often multifunctional and can seldom be ascribed a single function. Some roads serve as thoroughfares but pass through residential areas, some are shopping streets and residential streets with local traffic as well as through traffic, etc.

Consideration must be given to where through traffic should be routed and then to the matter of how to establish the greatest possible degree of safety when soft and hard traffic must flow together.

Many investigations have shown that speed has a significant effect on road safety, security and the environment.

The speed differential must not be excessive when soft and hard road users must share the same traffic area. In other words, if cyclists and vehicular traffic are to drive together, the speed on the road should not be much above 30 km/h, whereas if pedestrians and vehicular traffic must share the same area, the speed should not exceed 15 km/h.

The following road classification system has proved useful as a basis for setting priorities in road-safety promoting efforts and for determining the design of roads.

<u>Functional classification:</u>

- traffic roads	(through traffic)
- local roads	(local traffic)

<u>Speed classification:</u>

- traffic roads	* high speed	70-80 km/h
	* medium speed	50-60 km/h
	* low speed	30-40 km/h
- local roads	* medium speed	50-60 km/h
	* low speed	30-40 km/h
	* very low speed	10-20 km/h

On traffic roads, it is recommended that high speed be used very seldom, and then only when light road users are well separated from vehicular traffic. Low speed is recommended where there are many cyclists and there is no space for cycle lanes, where there are many pedestrians crossing the road and outside schools, shops and public service facilities.

On local roads, medium speed can only be used where there are few accesses or where there are few light road users. Very low speed should used on local roads and traffic areas where pedestrian activities are more important than vehicular traffic.

1.2 Conditions for designing individual roads

A road's function as a traffic road or local road and its speed class are set in the traffic plan. Apart from the significance of the road class for the geometric design, a number of other parameters will also affect the design:

- facade conditions
- parking conditions
- area needs of traffic
- road equipment conditions
- analyses of traffic accidents
- sight conditions
- the environment.

Facade conditions

Different types of area utilisation, such as shops, institutions or dwellings, set different requirements on the surrounding areas. Similarly, entries and exits from property - numbers and types - have great significance for the effective width of cross-section elements. Exit constructions that cross pavements and cycle paths require sufficient width for the ramp to the road surface.

Parking conditions

If a road is used for parking, consideration should be given to the question of whether or not parking should be maintained or be removed to specially-planned parking areas. Experience from a number of European countries has shown that, if attention is not given to the obvious need for parking, parking will take place in the light road users' areas.

Area need of traffic

Road users' physical area need when in motion is dependent on the dimensions of the individual road user and the quantity of traffic. The Highway Capacity Manual, 1994, gives an excellent description of the capacity parameters on stretches for vehicular traffic, whereas the capacity for light road users and the capacity at junctions must be based on national studies, due to its high dependency on behaviour.

It can be mentioned, for instance, that cycle capacity in China is 3 times greater than in Denmark. Quite simply, the Chinese cycle more closely together. Studies of capacity at roundabouts in Europe also show different and values in the different countries, depending again on behavioural differences.

But the capacity is obviously an important condition of geometric design, as it is decisive for the number of lanes and the width of the light road users' traffic area.

Analyses of accidents at roundabouts show that two access lanes or two exit lanes entail a higher accident rate than do single access and exit lanes. The reason is that road users conceal each other, thus limiting the free sight of circulating traffic.

If the capacity for cycle traffic is insufficient over a stretch, the fastest cyclists will tend to use the road instead of the cycle path. If the capacity of the pedestrian waiting area at pedestrian crossings is too low, pedestrians will probably stand on the cycle path or go out into the road, thus creating disturbances and risks, especially for cyclists.

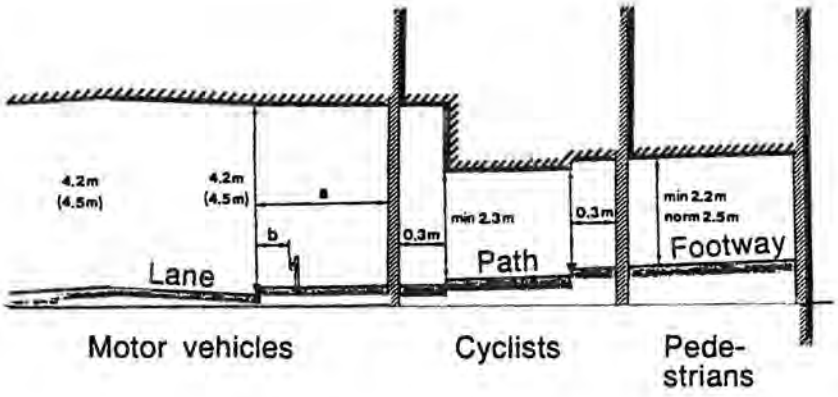
The dynamic area needs of vehicles are of considerable significance to the width of a road and to the location of road equipment. The maximum dimensions of normal vehicles are specified in EU directives, but there will always be exempted vehicles, such as certain wide items of agricultural equipment or especially long industrial vehicles.

The dynamic area needs of turning vehicles are of great significance to the geometry of junctions and to the safety of light road users. The faster a vehicle turns, the greater its area need and the greater the risk of overlooking cyclists and pedestrians. At the same time, large turning areas entail large junctions, which can result in reduced capacity, especially at junctions controlled by traffic lights.

Road users need more space when they are in motion than when they are stationary. Consideration must be given to this when locating fixed objects. such as road equipment.

Where cyclists are concerned, all protruding objects should be considered to be fixed. as even a pedestrian or marking cone can topple a cyclist.

Every effort should therefore be made to ensure that road equipment is located at a suitable distance from the kerb and edge of the cycle path. The figure below is reproduced from the Danish Guidelines for Geometrical Design.



Speed class:

Heigh	a ≥ 3,00m	b ≥ 1,00m
Midle	a ≥ 1,00m	b ≥ 0,75m
Low	a ≥ 0,50m	b ≥ 0,50m
Very low	a ≥ 0,25m	b ≥ 0,50m

Figure: Distance to obstacles

Road equipment conditions

Road signs and markings

Road signs and markings are used to guide road users and should therefore be located so that it is possible for road users to read and understand the information to be imparted in sufficient time to take the appropriate action. This sets requirements on the geometric design of road constructions. Thus, road signs and markings should be considered to be an integrated part of the geometric design. This is unfortunately practiced all to rarely in Europe, where there is a clear impression that the road designers first started to consider the need for road markings after road geometry was specified.

Serious accidents can result, for instance, if direction signs, prohibitions or traffic lights are observed too late.

In this context, it should be mentioned that advertisements, the true purpose of which is to attract attention, can disturb road users' capacity for reading and understanding the information that the authorities wish to impart to them for the sake of road safety. Unfortunately, the influence of advertisements on road safety has not yet been sufficiently investigated.

Road lighting

In urban areas, the primary purpose of road lighting is to ensure that weak road users can be seen, that they can see the state of traffic areas at night, to offer security against attack, etc.

The level of illumination should be suited to the road class and, thus, should always ensure that road users can see far enough ahead to be able to stop at an obstruction.

But, when an accident occurs, street lighting and other large items of road equipment can be dangerous objects, if they are involved in collisions at speeds of over 40 km/h. Thus, on roads in the medium- and high-speed classes, consideration should be given to locating lamp posts as far from the road as is economically feasible, or to equipping them with break-away safety devices. Where light road users would be exposed to danger if a lighting post should collapse as a result of an accident, the choice of break-away safety devices should be assessed on the basis of a thorough risk analysis.

Analyses of traffic accidents

An accident analysis should be conducted before any alterations to a stretch of road, a junction or other traffic area.

Accident analyses are an important requisite to understanding what can be wrong with road constructions, and they should be conducted regularly throughout the functional life cycle of such constructions. Such analyses should be based on accident reports, road and traffic data and inspection at site.

Concerning geometric design, it is especially important to study:

- clearness
- visibility conditions
- optical guidance
- the visual environment
- road user behaviour
- road markings
- vertical sign markings
- other traffic conditions that cannot be determined from available traffic data.

If accidents occur as a result of excessive speed in relation to the planned speed - the reference speed - attempts should be made to reduce the speed with the aid of physical speed reducers.

If accidents are due to changed or impaired sight conditions on a stretch of road or at a junction, it will be necessary to assess whether or not conditions can be brought into harmony with the reference speed or whether the reference speed should be reduced to correspond to the attainable sight conditions.

2. Design of road elements

Once the categories of road user on a stretch, road class and speed class have been defined in the traffic plan, and when pilot studies have determined the number of lanes, bus lanes, parking lanes, whether or not a cycle path should be laid, pedestrian areas, road equipment plan, speed reduction, etc., there is a basis on which to do the detailed design of the traffic areas, ie alignment elements, cross-section elements, design of junctions and selection of types of speed reduction.

Alignment Elements

There are only limited degrees of freedom when choosing alignment elements - gradient, vertical curves and horizontal curves - in established urban areas. The surroundings have normally set a fixed framework.

But one factor decisive for road safety is that sight is sufficient to permit road users to stop if there are obstructions on the road, or to carry out safe overtaking where there is oncoming traffic and overtaking is permitted.

The condition for being able to determine the necessary free-sight area is that the underlying traffic parameters are known.

This is a matter of:

- vehicle height
- eye height and location in the cross section
- object height and location in the cross section
- braking reaction times
- coefficients of friction
- cycle speeds
- pedestrian speeds.

It should be noted here that it is important to be able to ensure not only free sight for motorists, but also for light road users. Many accidents between light road users occur because they cannot see each other in time to stop. And accidents involving light road users are often serious.

Cross-section elements

The width of the traffic area in established urban areas is often determined in advance, ie the distance from facade to facade. Where it was common in the 1960s to demolish buildings out of consideration for free passage and accessibility to vehicles, it has become more common in the 1990s to adapt the traffic to its surroundings.

The art is therefore to find the space for the cross-section elements specified in planning.

The width of the road depends partly on the prevailing speed and partly on the types of vehicle that will use the road.

Speed		Lanewidth
High	(70-80 km/h)	3,5 m
Middle	(50-60 km/h)	3,00-3,25 m
Low	(30-40 km/h)	2,75 m
Very Low	(10-20 km/h)	2,5 m

Figure: Lanewidth

If. under exceptional circumstances, cycles will use a medium-speed road (50-60 km/h), the lane width should be increased by at least 1.0 m and it should be marked with a cycle lane.

If special vehicles will use the road, it is important from the standpoint of vision to maintain the road width shown in the figure and to ensure accessibility for the special vehicles by locating road equipment outside the free-area requirement and, possibly, by establishing special run over areas for these vehicles.

Cycle paths

The widths of cycle paths depend on the quantity of cycle traffic and on whether the cycle path is one-way or whether it is part of a divided path.

The minimum width determined with a view to facilitating overtaking on a cycle path is 1.7 m. for a one-way cycle path.

Pavements

The width of a pavement depends on the quantity of pedestrian traffic. The minimum width is 1.5 m and is based on the width needed for a wheelchair and perambulator to pass each other.

Middle islands

Middle islands that are located on roads to separate the traffic travelling in opposite directions, and to ease crossing the road for light road users. should be broad enough for the longest of these road users. for instance. a cyclist. to stand in the shelter of the island without extending into the traffic lanes.

Kerbstones

Kerbstones should be designed so that they do not comprise a significant risk in the event of a collision and so that light road users cannot suffer especially serious injury by falling on a kerbstone. Faceted kerbstones are normally safer than kerbstones with sharp edges.

When using the minimum dimensions for the various cross-section elements, it is important that they are not used simultaneously. It is also important that cross-section elements be designed so well that the specified width is maintained throughout the life cycle of the entire element. In other words, the specified area must not be reduced by cracks, unevenness, holes or pools of water.

Intersections

Road safety

Consideration for road safety should be given top priority when deciding on the location of a new intersection, the choice of intersection type in general and the detailed design of intersections and their surroundings.

Driving across intersections usually involves complex manoeuvres, during which drivers must continuously assess the positions, speeds, etc., of other road users. It is vital to road safety that drivers be given sufficient time to perceive situations and to adjust their speeds accordingly.

In established urban areas, and when reconstructing roads, the design of intersections will usually be decisive for the permissible speeds. It may therefore be necessary to support a desired speed with physical and optical measures at the intersections.

Most importantly, road users approaching an intersection must become aware of the intersection early enough to prepare for the necessary changes in their driving patterns. Road users on the minor road need information on the prevailing priorities soon enough for them to give way, and road users on the major road must also be given a clear and timely idea of the priorities ahead.

Visibility must be good for all road users, especially from the minor road to the major road, along the major road (for major-road users turning left) and to the rear, (for major-road users turning right).

Drivers should be able to position themselves before reaching the intersection, and it should be easy to choose direction and the appropriate lane once in the intersection.

Due respect should also be given to light road users, ie pedestrians, cyclists and moped riders. This is partly because these road users constitute a high-risk group and their injuries are often severe, and partly because their behaviour on the road is less orderly than that of vehicular traffic and because even small inconveniences, in the form of detours and suchlike, can cause inappropriate behaviour at intersections.

Location of intersections

An intersection should be established in a dip and preferably in a concave vertical curve for both roads. If this is impossible, it should first and foremost apply to the minor road.

Intersections are best constructed on straight stretches and under no circumstances in sharp horizontal curves. Joining a road on the inner side of a curve can result in poor visibility of other vehicles. Joining a road on the outside of a curve with superelevation can impede minor-road users' perception of an intersection and it also results in an inappropriate transverse inclination of turning vehicles.

Intersections should be located so that the prevailing physical conditions permit the establishment of the visibility splays shown later in this paper.

Indication of intersections

Intersections should be designed to be visually differentiated from free stretches. This applies just as much to their surroundings.

This is mainly achieved by suitable interruptions of the optical alignment, by the provision or discontinuation of plantings, by the judicious siting of posts, etc., and by the erection of road signs and markings.

The discontinuation of kerbstones, the provision of traffic islands, staggering and, possibly, narrowing, can all contribute to the visual indication of an intersection.

Priority conditions should be unambiguous. The minor road should therefore follow an interrupted course and, in the case of "F" intersections (four-way intersections), it is vital to avoid misleading road users with kerbstones, plantings, illuminators, etc., that remain unchanged after the intersection. This is particularly important when the facades on both sides of an intersection look alike.

When priority conditions at an intersection are changed, the alignment of the former major road should also be changed, so that the new priorities appear clearly. The continuation of the minor road can be concealed by plantings and an interrupted alignment can be emphasised by staggering the intersection and changing the lighting system.

If a minor road swings to the right shortly before a junction, perception of the intersection can be ensured by locating a traffic island that visually obstructs the access lane.

Design of intersections

When designing intersections, an architectural balance should be sought between the street space and the surroundings, and the different elements should be utilised.

Based on the above requirements of orientation, visibility, etc., certain other general requirements can be set on the design:

- only a few, easily recognisable, elements should be used;
- the junction between the minor and major roads should be as close to a right-angle as possible;
- when halted, minor-road users should be waiting approximately at right-angles to the major road;
- at all points in an intersection, road users should have adequate visibility ahead, so that they can choose the correct lane.

In intersections where the flow of traffic turning between two of the branches is significantly greater than the through traffic or the traffic turning between the other branches, it may be desirable to give higher priority to this traffic flow. In such case, the intersection should be redesigned so that the road geometry clearly shows the direction of the main traffic flow. This would make the priority unambiguous.

Where the design of an intersection is intended to reduce the speed of vehicular traffic, the following elements can be used:

- narrowings
- staggerings
- central traffic islands
- ramps and raised carriageways
- humps
- changed road surfaces
- demand-actuated lights.

The position of road equipment, signs and road markings should be an integral part of the geometric design of intersections. In connection with this, care should be taken to check that:

- road markings, road signs, direction signs and any traffic lights can be seen and understood in due time by the target road users;
- road equipment (signs, shelters, lamp posts, plantings, etc.) does not impair visibility;
- clearance requirements can be satisfied.

Types of intersections

The general design of an intersection is determined by a large number of factors, such as:

- the number of branches in the intersection;
- the number of lanes on the intersecting roads;
- the existence of cycle paths or lanes on the roads;
- provisions for pedestrians (pavements, zebra crossings, traffic islands);
- priorities;
- control by traffic lights.

Categorisation of intersections into types, on the basis of the full range of variation of all these factors, would result in an extremely large number of types. For the sake of simplicity, the distinction is limited to a few basic types, ie:

- intersections controlled by traffic lights
- priority-controlled four-way intersections, "F"
- priority-controlled three-way intersections, "T"
- raised side-road junctions
- roundabouts
- uncontrolled intersections.

Over the past 5 to 10 years, roundabouts have become extremely popular in Europe. Experience of capacity and road safety has been good (especially for hard road users) in countries where entering traffic must give way to circulating traffic. In comparison with crossings controlled by traffic lights, there are no fewer accidents involving cyclists at roundabouts, but the accidents that do occur tend to be less serious.

Complete agreement has not been reached on the best approach to roundabout design from the standpoint of safety - probably because of differences in traffic culture. Especially in the case of cyclists, accident analyses show that, although similar types of accident occur, different safety approaches are taken by different countries. Typically, accidents in which cyclists are involved occur between circulating cyclists and entering/exiting vehicles.

However, there does appear to be a consensus that when cyclists use roundabouts, the roundabouts must be designed to have a speed-reducing effect, so that the speeds of vehicles are reduced to 15-20 km/h. At this speed, it is easier for motorists to notice circulating cyclists. At the same time, there should not be more than one lane entering and one lane leaving the roundabout, for the reason mentioned above, ie so that motorists do not obscure each other's view.

Free sight at crossings

Care must always be taken to ensure that road users who must give way can see the road users to whom they must yield. This applies equally to drivers of vehicles - including the drivers of trucks in their high seats, cyclists and pedestrians.

A visibility splay should therefore be established to ensure conflict-free passage of crossings.

The size of visibility splays depends partly on the reference speed on the major road, the speed of cyclists on the cycle path and the speed of pedestrians, and partly on the conditions built into the model, such as eye height, location of objects, braking reaction times and the deceleration times of vehicles.

Here, it is vital that turning vehicles have the necessary view to left and right, and ahead and to the rear towards cyclists.

Where the necessary free sight cannot be attained because of obstructions within the free-sight area, it is necessary either to modify the geometry of the crossing, the crossing type or to reduce the reference speed on the major road.

Speed reduction

The relationship between speed, accident risk and degree of seriousnees of accidents is well known. If the traffic plan specifies a reference speed that is not respected by road users, it becomes necessary to use speed-reducing measures.

The are two main types of speed-reducing measure:

* visual speed reducers
* physical speed reducers.

Visual speed reducers include road markings, psychological aids, such as closed road spaces (with trees, gates, buildings, etc.) and attractive design of the street space (walls, floor and ceiling).

Experience shows that the visual speed reducers generally have a limited speed-reducing effect. Their effect is, of course, good in countries where speed limits are observed by road users.

Physical speed reducers include rumble strips, narrowing of the road, staggering or humps.

Of these measures, humps are the most effective, but also the most unpopular among road users - especially bus drivers.

However, Danish experience shows that, if humps are designed so that road users do not feel that they are being punished as they pass them at the signed speed limit, bus drivers will also accept them. The figure shows how humps can be designed so that they will be accepted. When passed at the set speed limit. the driver is exposed to a vertical acceleration of 0.7 G.

Speed	Chord length	Bus speed
20 km/h	3.0 m	5 km/h
25 km/h	3.5 m	10 km/h
30 km/h	4.0 m	15 km/h
35 km/h	5.0 m	20 km/h
40 km/h	6.5 m	25 km/h
45 km/h	8.0 m	30 km/h
50 km/h	9.5 m	35 km/h

Figure: Design for humps

When installing speed reducers, it is important from the standpoint of the environment (air and noise pollution), and for the acceptance of road users, to ensure a constant speed profile. Experience shows that too great a distance between speed reducers causes violent acceleration and deceleration on the stretches.

Visual environment

An attractively designed street space gives road users a pleasant experience and attitude to travelling along a street. Experience from most of the world shows that beautiful objects give rise to beautiful thoughts, and that vandalism and violence are rare in such places.

Beautiful design need not be costly - indeed, it is often merely a question of choosing the right materials.

Roadside safety

Fred Wegman
SWOV Institute for Road Safety
Research, the Netherlands

SWOV

National Cooperative Highway Research Program (USA/TRB)

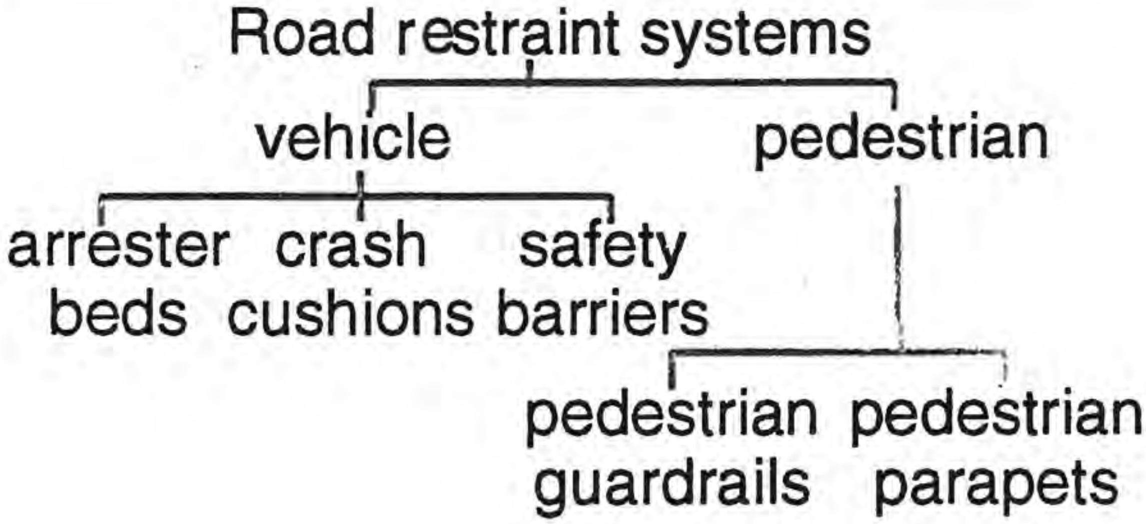
- NCHRP Report 350

- Recommended procedures for the safety performance evaluation of highway features

European Committee for Standardization

- CEN/TC 226 Road equipment
- Working Group 1 Road restraint systems
    - part 1
      Terminology and general criteria for test methods
    - part 2
      Safety barriers

Terminology



Road restraint systems

vehicle

pedestrian

arrester beds

crash cushions

safety barriers

pedestrian guardrails

pedestrian parapets

Arrester beds : decelerate and arrest errant vehicles (long downhill gradients)

Crash cushions : energy absorbtion device (rigid object)

Safety barriers : road vehicle restraint system (alongside of a road)

Pedestrian guardrails : restraint system for pedestrians

Pedestrian parapets : restraint system along the bridge/wall

Design of safe verges

- design obstacle free zone

- single obstacles:
    - ○ remove rigid obstacles
    - ○ use "harmless" obstacles
    - ○ protect rigid obstacles
        - ▪ crash barrier
        - ▪ impact attenuator

- design full protected zones

design for
- ○ car occupants
- ○ "third' parties

Impact test acceptance criteria

- Safety barrier behaviour
  - contain and redirect the vehicle without breakage
  - no part shall become detached
  - no part shall penetrate passenger compartment
- Test vehicle behaviour
  - not underride or override
  - remain upright
  - limited exit angle
- Severty index
  - ASI and THIV below max. values
- Test vehicle deformation
  VCDI
- Safety barrier deformation
  - limited dynamic deflection

Containment levels

Containment levels		Acceptance test
Containment for temporary safety barriers only	T1 T2 T3	TB 21 TB 22 TB 41 + TB 21
Normal containment	N1 N2	TB 31 TB 32 + TB 11
Highter containment	H1 H2 H3	TB 42 + TB 11 TB 51 + TB 11 TB 61 + TB 11
Very high containment	H4a H4b	TB 71 + TB 11 TB 81 + TB 11

Vehicle impact test criteria

Test	Impact speed (km/h)	Impact angle (degrees)	Total vehicle mass (kg)
TB 11	100	20	900
TB 21	80	8	1 300
TB 22	80	15	1 300
TB 31	80	20	1 500
TB 32	110	20	1 500
TB 41	70	8	10 000
TB 42	70	15	10 000
TB 51	70	20	13 000
TB 61	80	20	16 000
TB 71	65	20	30 000
TB 81	65	20	38 000

Impact severity levels

Level			
A	ASI ≤ 1.0	and	THIV ≤ 9 PHD ≤ 20g
B	ASI ≤ 1.4		

(CEN, 1994)

ASI : Accident Severity Index

THIV : Theoretical Head Impact Velocity

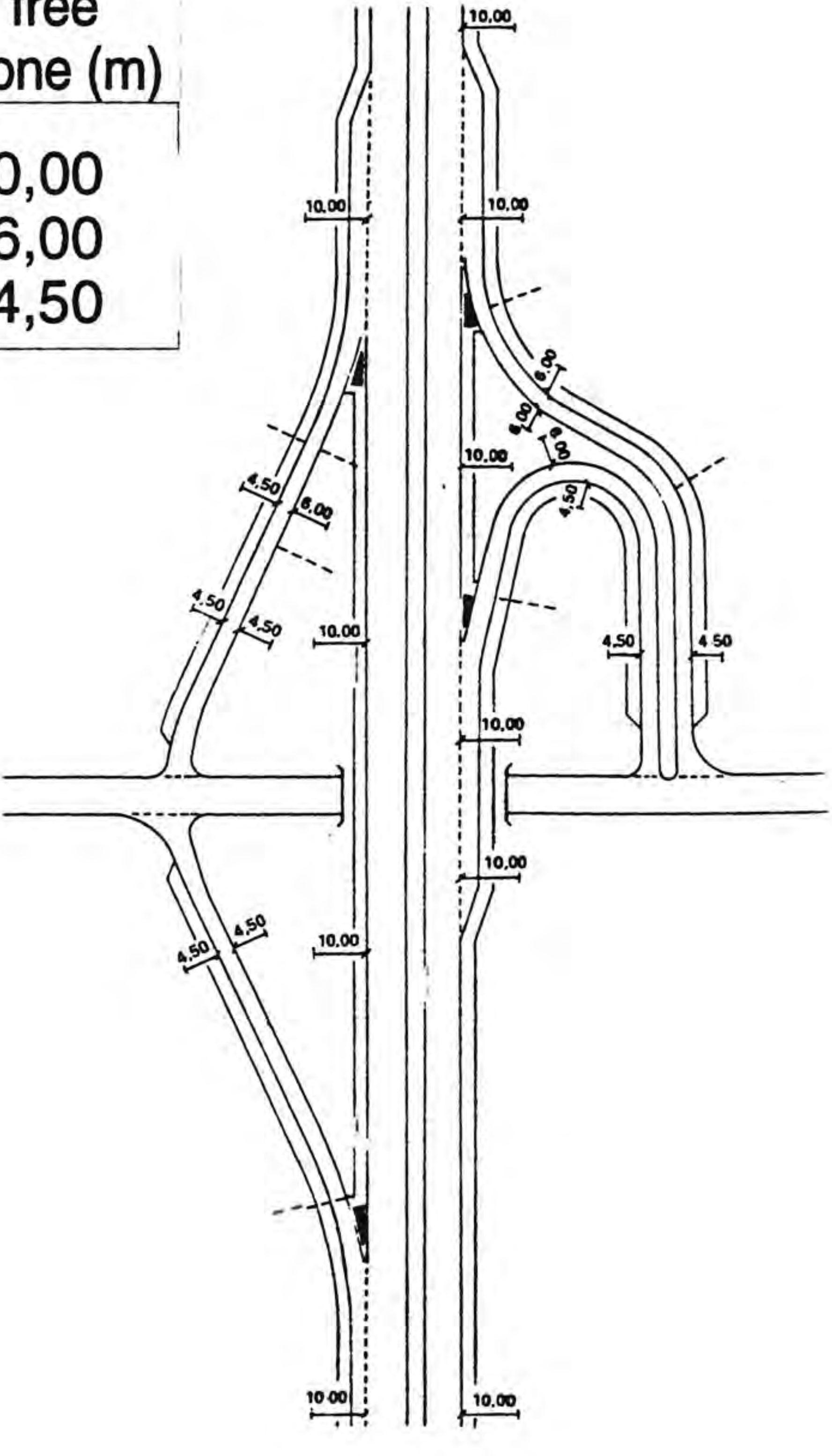
PHD : Post-impact Head Deceleration

Deformation of the restraint system

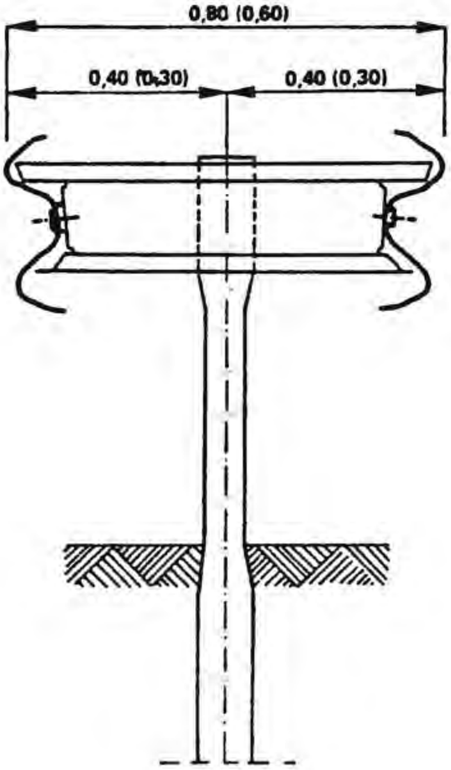
Classes of working width levels	Levels of working width (W)
W1	W ≤ 0,6
W2	W ≤ 0,8
W3	W ≤ 1,0
W4	W ≤ 1,3
W5	W ≤ 1,7
W6	W ≤ 2,1
W7	W ≤ 2,5
W8	W ≤ 3,5

Obstacle free zones (Dutch manual)

speed km/h	obstacle free zone (m)
90 ≤V ≤ 120	10,00
60 ≤ V ≤ 90	6,00
V ≤ 60	4,50



Guard rails



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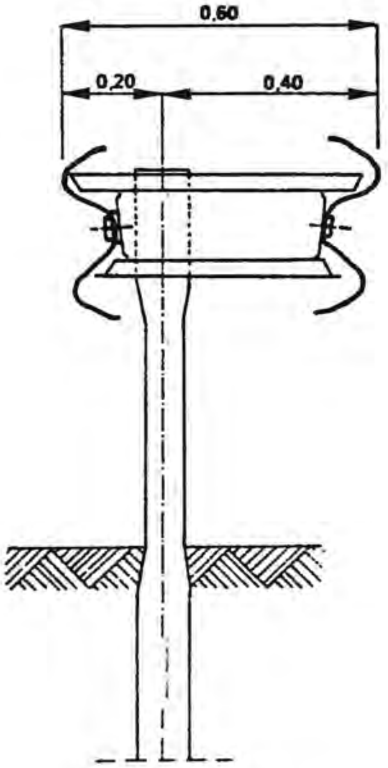

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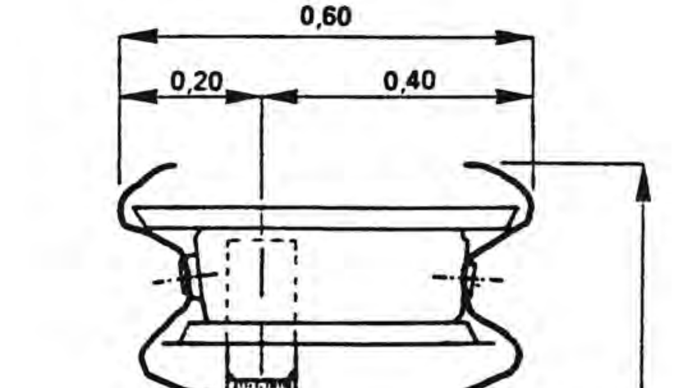
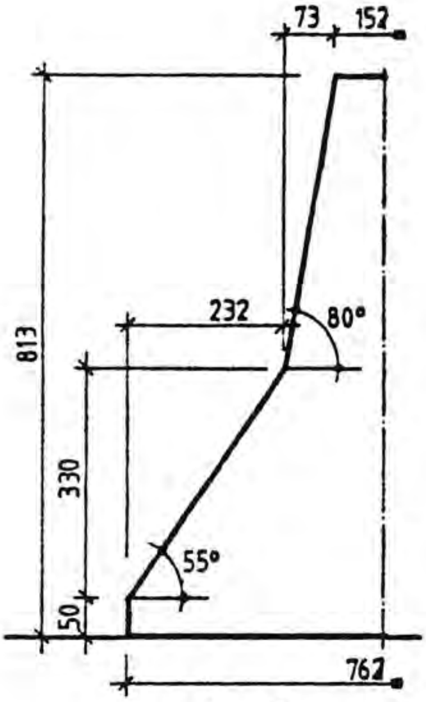
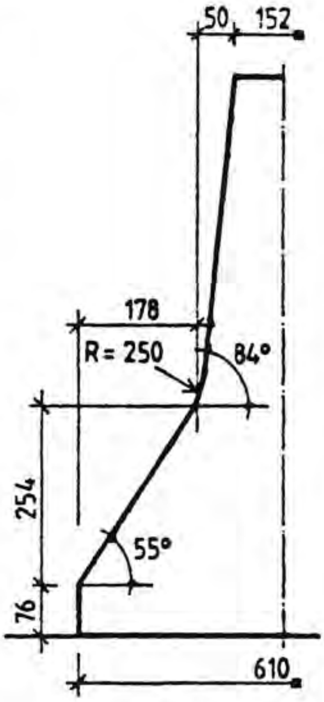


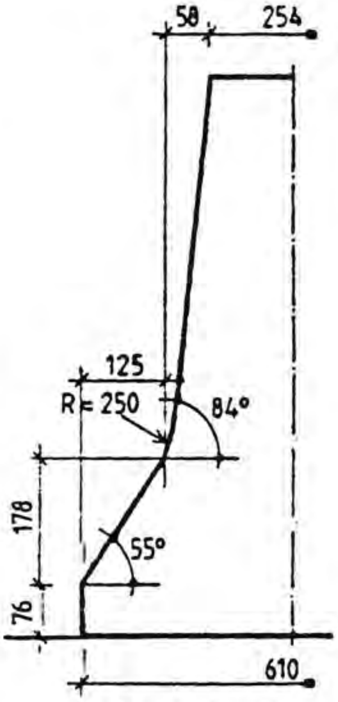
Concrete barriers



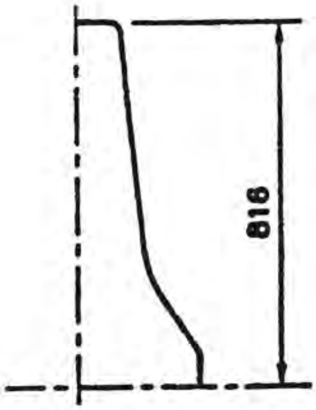
general motors
(maten in mm)



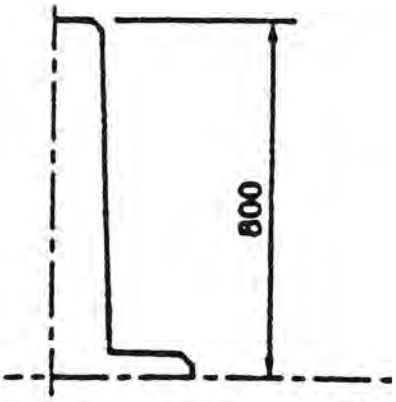
new jersey



configuration - F



British Concrete Barrier

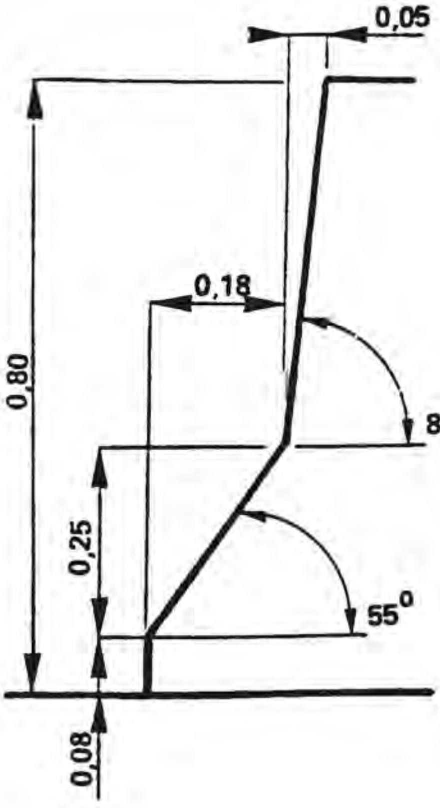


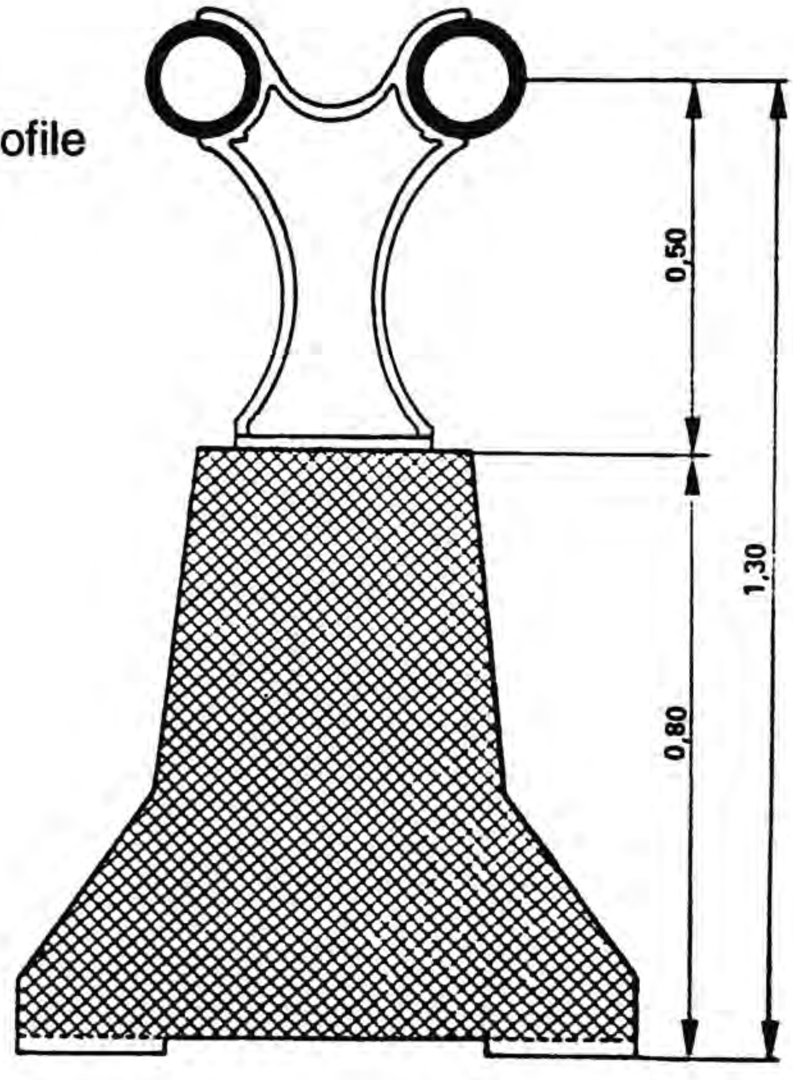
Vertical Concrete Barrier

Concrete barriers

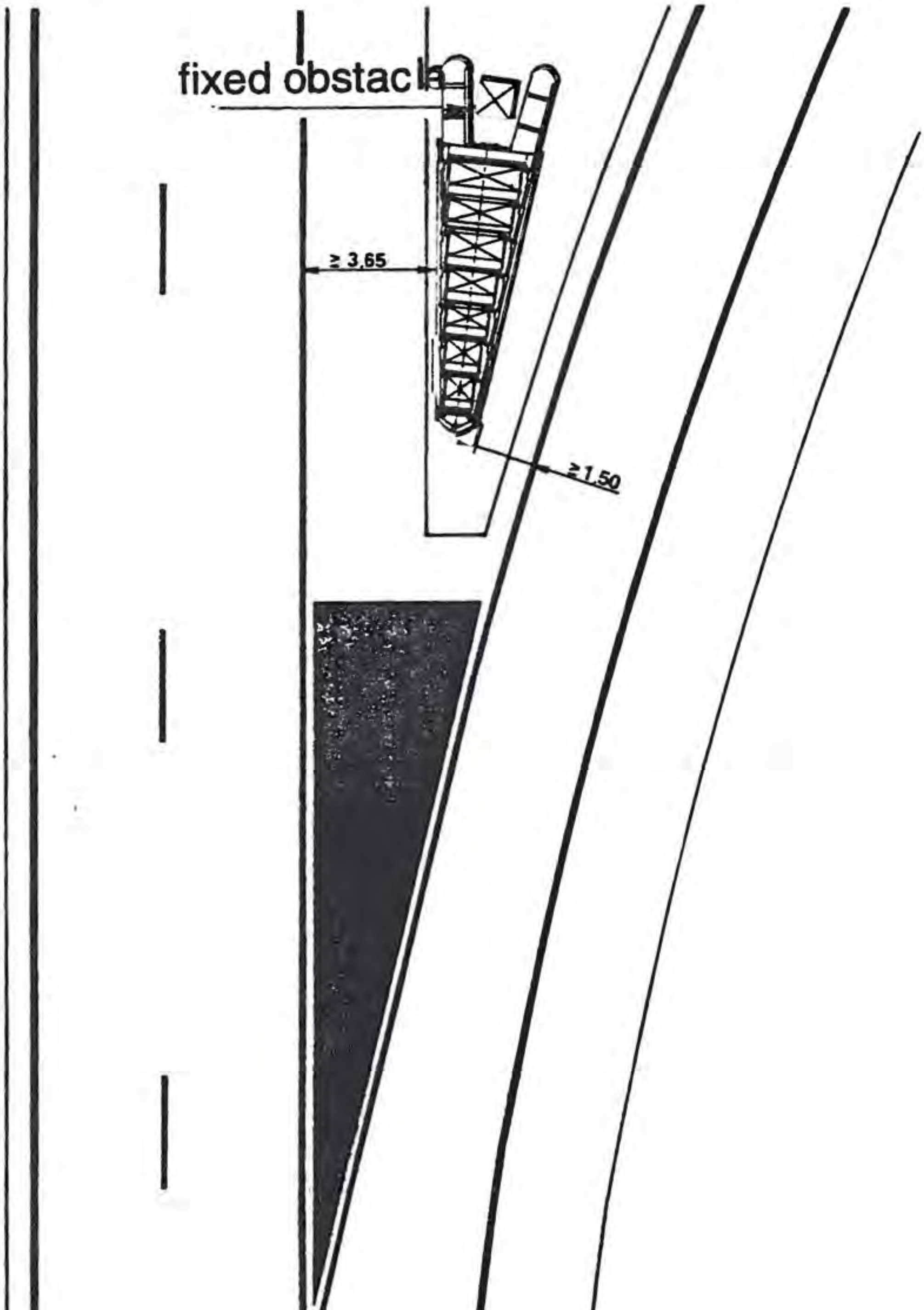
heightened barrier

New Jersey (NJ) profile





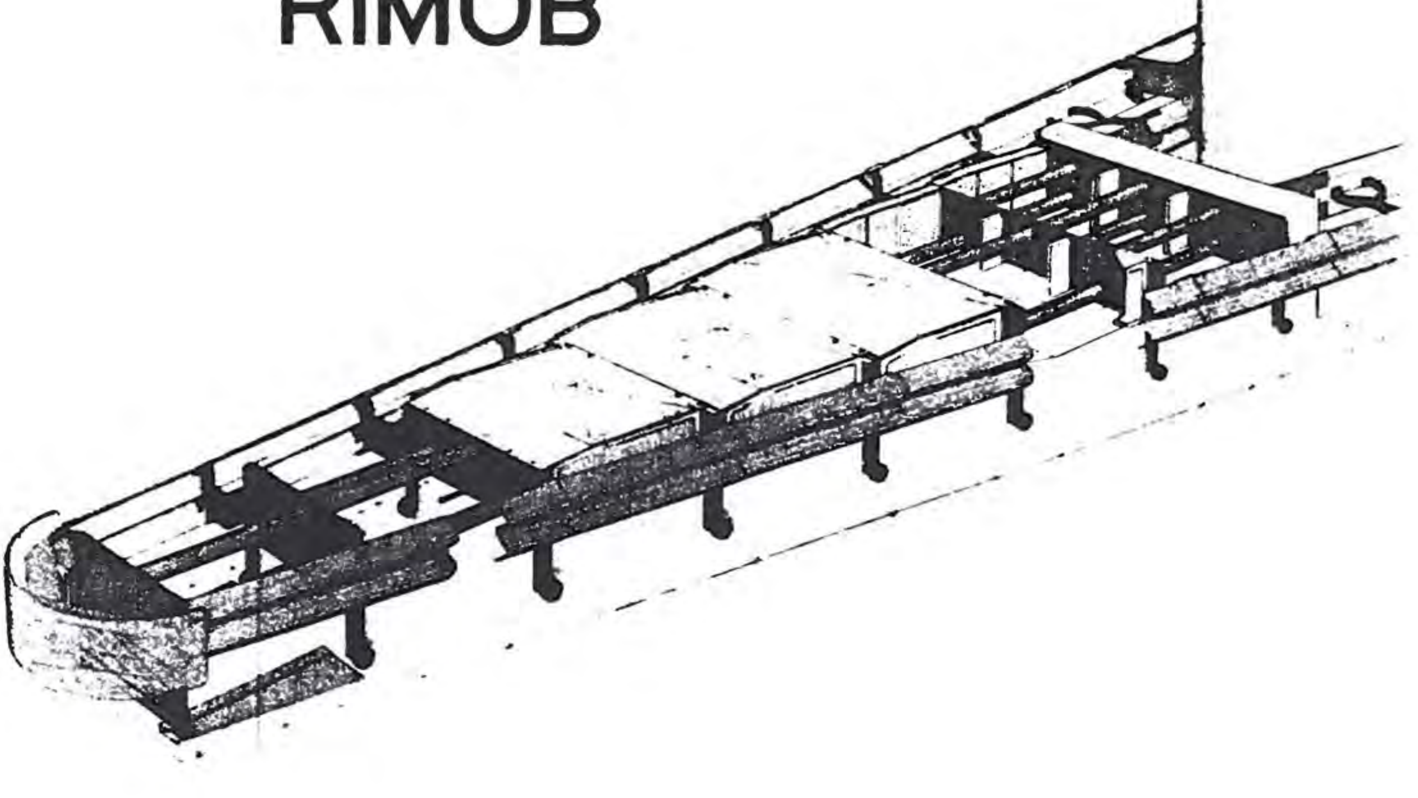
Impact attenuator



Impact attenuator RIMOB

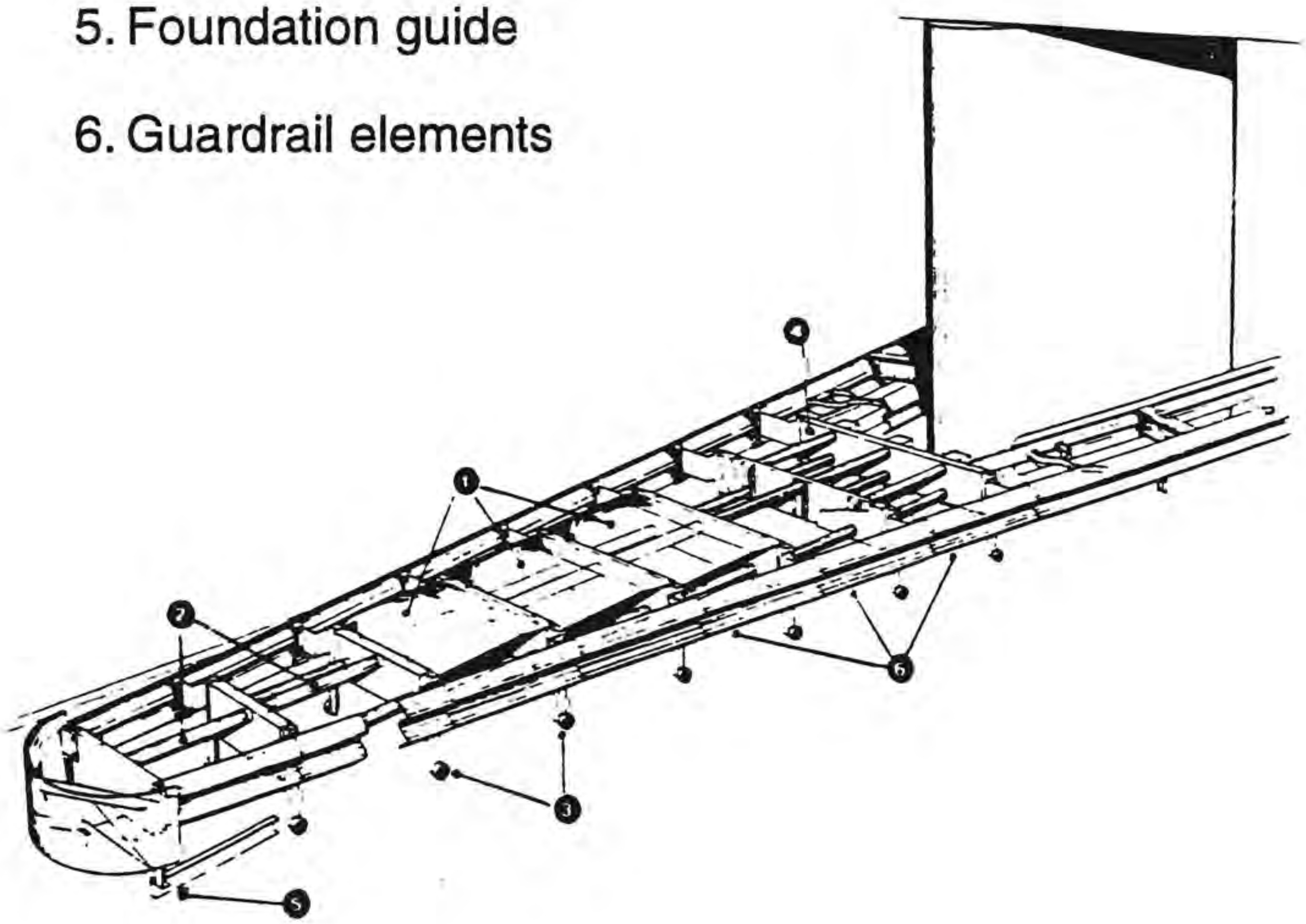
[illegible] BEVEILIGINGSCONSTRUCTIE

RIMOB



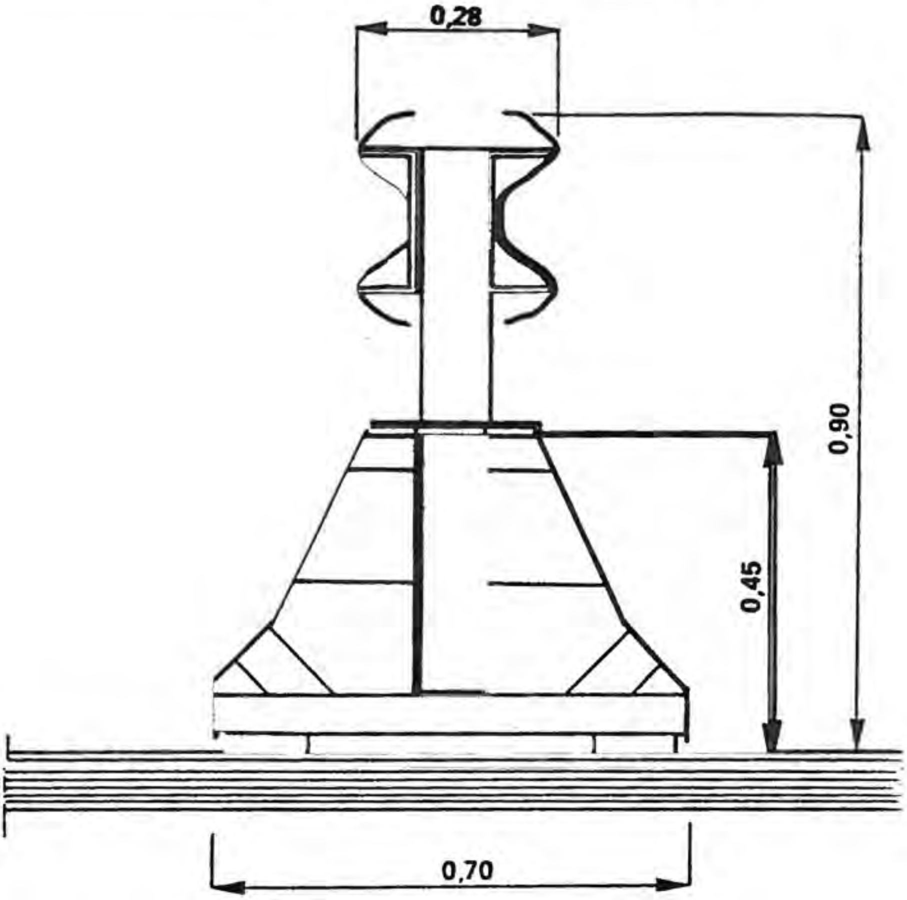
Impact attenuator RIMOB

1. Box segments
2. Aluminium crumpling tubes
3. Posts with wheels
4. Foundation support
5. Foundation guide
6. Guardrail elements



Working zones

- Vecu-sec
- Mini-guard
- Vario-guard
- Bever
- Safe-guard
- RWS-barrier



OECD Workshop B3 on
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Prague, Czech Republik, 15-18 November 1994

Black spot approach

Marinus (Pim) Slop
Prague, Czech Republik, 17 November 1994
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Aim of black spot analysis

The aim of a black spot **analysis** can be described as:

> To find indications for improving the *layout* of an accident prone location, by studying similarities between features of the accidents occurring on that location.

Analysis is primarily based on *accident* data, together with data on traffic, infrastructure and road environment. No consideration of near accidents, conflicts, fear for accidents or subjective feelings.

The analysis is to be followed by **treatment** of the black spot, generally consisting of *traffic engineering* measures (constructional or operational), **not** of educational measures, advertising campaigns, intensified enforcement, etc.

Motivation

A single cause of a specific accident can seldom be indicated. One can mostly distinguish many circumstances and/or events that have contributed to the occurence of the accident. These may all be regarded as a 'cause' of the accident. How do we know which one we should eliminate as the cause of future accidents?

The best approach is to combat combinations of circumstances and/or events that apparently often lead to accidents or often occur at accidents. But the circumstances and/or events vary from place to place. So, the necessary analyses must be repeted.

Registration

To be able to study accidents (not necessarily on black spots) it is necessary that accidents are *registered*. Normally, this is done by the police. Registered are:

- accident data, like exact time and location, information on colliding vehicles, drivers, manoeuvres, collision type, damage, injuries, etc.
- data on road and circumstances, like detailed situation (with drawing), light, weather, road surface conditions, etc.

But subsequent analysis of these data is hindered by the following circumstances:

1) Not all accidents are registered:
    - in Western Europe only the fatalities for almost 100%;

    - the lesser the injury the lower the proportion registered;
    - light injuries around 10% only;
    - material damage only accidents probably even less.
2) The underregistration is not equally distributed: the percentage is lower for accidents where no motor vehicle occupant was injured.
3) Parts of the registration may be erroneous if the accident was complicated.
4) Not all relevant data are registered, p.e.
    - driving speeds before the accident;
    - driving experience of persons involved;
    - safety belt use.

When analysing the accident data problems can partly be reduced by collecting data from several years together.

Accident data are filed in national databases from which every information can be drawn by road administrators (sometimes also by private researchers). You usually have to pay for this. There are a number of standard output formats which can be further processed by using computer software.

Also available are digital files of (parts of) the road network. Accidents may be plotted on such a part of the network.

Selection of black spots

Black spots on a road network are locations with high accident records; these topographical accident concentrations may be junctions (usually), but also short road sections, p.e. bends.

Black spots may efficiently and effectively be identified by retrieval from the *systematic accident registration* in the database. A usual output is a list of hazardous locations in a jurisdiction, in the order of decreasing number of accidents. There is usually an arbitrarily chosen threshold, p.e. 10 to 12 accidents in total, or 6 to 8 accidents of the same type, all within a period of 3 to 5 years.

The accidents may be weighed, p.e.:

fatality	10
hospital admission	5
other injuries	3
material damage only	1

This is only a help to make differences more pronounced; the threshold values change accordingly.

Sometimes locations are selected on the basis of a *specific accident feature* often occurring; p.e. young children as victims, heavy vehicles involved, alcohol usage, etc. (N.B. In the subsequent analysis, all accidents must be included!). This is especially the case when spearheads of attention have been formulated by the local government.

To be able to make such selections, average figures must have been calculated as a reference to compare with.

All activities up to this point can be done by people having no specific knowledge of traffic engineering.

Black spot analysis method

Once the black spots have been selected, analyses of the black spots can be made. The description here is mainly based on the method that has been used for 15 years in the Netherlands. This method is not essentially different from that in other Western European countries, p.e. the United Kingdom and France.

The analysis does not necessarily start with the black spot having the worst record.

The entire method consist of 7 steps.

1. Data collection

a. *Accident* data - 3 to 5 years

b. *Traffic* data: volumes, composition, speed(?)

c. Data on the *situation*: large scale map (1:200 to 500); reconstructions?, changes in circulation?

From a+c: collision diagram: grouping accidents according to place and type

Accident table; see example

2. Data analysis

Search for dominant types of accidents, p.e. 5 or more accidents of the same type?

Within dominant types, search for dominant accident features

Examples:
a. many accidents when road surface wet
b. priority rule often neglected by drivers from one particular leg
c. all drivers involved drove straight ahead
d. no accident concentration according to time

3. Formulating hypotheses

Difficult! But:
lists exist of possible hypotheses going with the most occurring accident types.

Examples:
a. longer braking distance: road surface o.k.?
b. junction poorly visible from this leg
c. too high approach speeds
d. traffic volumes not important

4. Hypothesis testing

- supposed shortcomings in layout, construction or use
- on location *(N.B. Do not visit the location before! Up to this point in the process, the information should only be derived from accident registration)*
- as a driver under relevant conditions

5. Additional investigation

if necessary

P.e. in-depth collection of accident data:
- by looking into original police records
- by interviewing persons involved
- by interviewing frequent passers-by
- by adequate monitoring traffic behaviour

6. Establishing accident causes

Probable accident causes!

7. Proposing countermeasures

(N.B. Do not jump to this point from step 2!)
- must take away probable causes
- take care of adverse side-effects!
  (p.e. no speed reducing humps on 70 km/h roads with the aim of improving priority behaviour)
- mostly choice out of two or more possibilities
- various countermeasures must match
- changing the layout (or regulations) if shortcomings have been discovered
- only if this is not possible or excessively expensive, then other countermeasures are more likely: education, information, enforcement (no part of the method)

Evaluation

-> to be better able to estimate the effect of future countermeasures

Before/after study: at least 3 years before, 3 years after.

Problems (the most important of which will be dealt with by G Maycock):
1) Accidents occur at random; the real effect of the countermeasure is to be distinguished from the random variation.
2) Regression to the mean.
3) Possible change in registration level before/after.
4) Correction for general development in figures -> control group needed.
5) Possible change in the road functions.
6) Possible changes in accident types as a result of the countermeasure (p.e. after installing traffic lights)
7) Accident migration.
8) Habituation period.

Nevertheless: monitoring must start immediately after the countermeasure being taken: unexpected adverse side effects are possible -> additional measures or even back to original layout!

Several possibilities:

Countermeasures	1	>1	1	>1
Locations	1	1	>1	>1
Accident types	≥1	≥1	1	>1

Average reductions:
France: accidents 50%
casualties: 50-65%

The Netherlands:
casualties: 55%

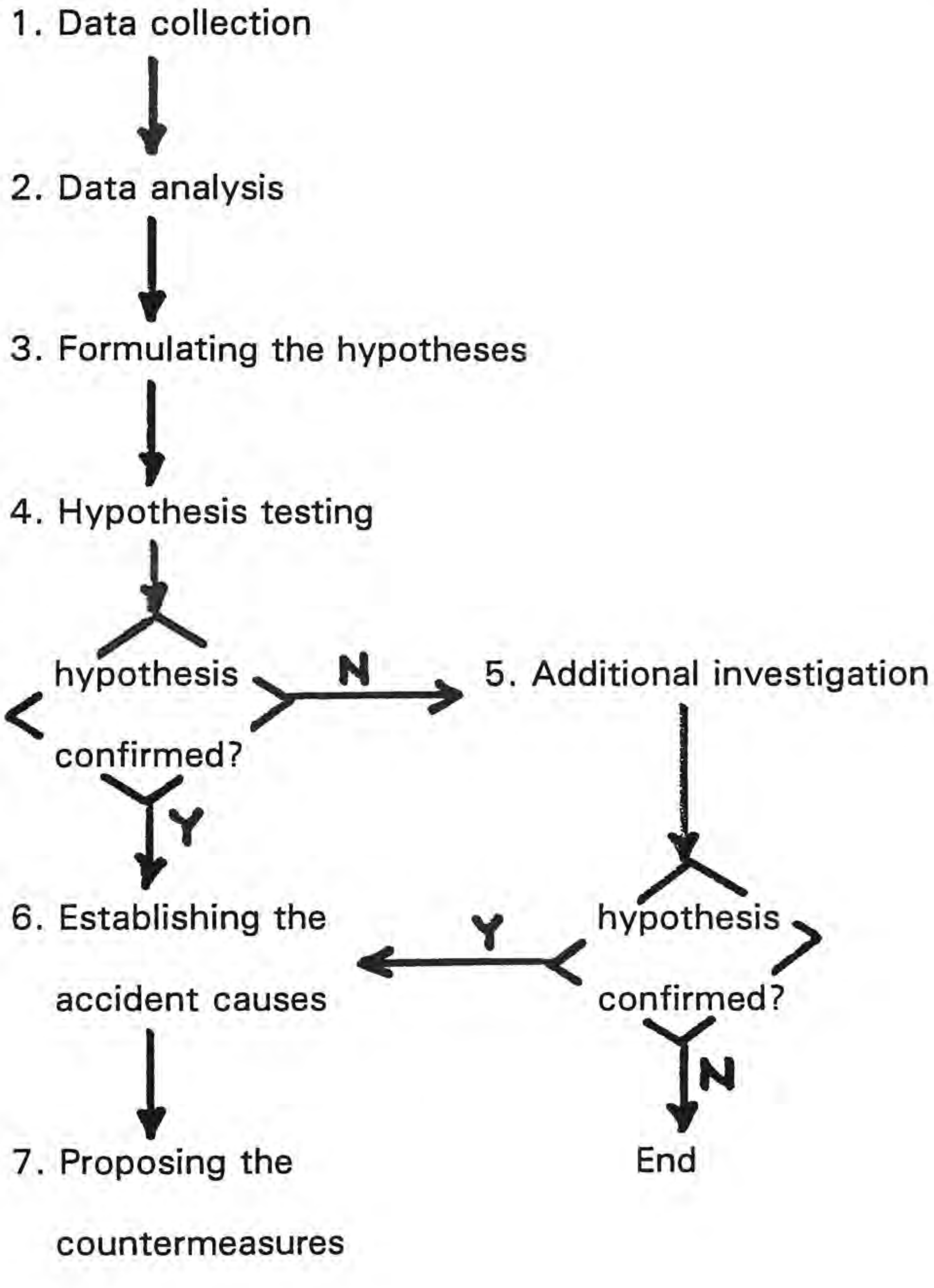
Recent trends

About 20% of all accidents occur on black spots. So, even if all accidents on all black spots could be prevented, the total number of accidents would only be reduced by 20%. In reality, not all accidents on black spots are prevented by treating the black spots. Therefore, the benefit is lower.
If, moreover, the policy target is a reduction of more than 20%, it is clear that the black spot approach only is not sufficient.

For this reason, complementary methods were recently developed in the Netherlands, which no longer require a topographical concentration of accidents. But, to carry out a statistical analysis, some way of bundling the accidents is always necessary.
In one method, this bundling is accomplished by taking the accidents in a limited area or on a route together, so larger numbers of accidents and also more types of accidents can be investigated. The subsequent analysis is quite different from the black spot approach. Instead of starting by collecting the accident data the emphasis is laid on the discrepancies between the intended functions of the area or route, and the actual functions.
Another method looks for a bundling of accidents that show one or more common characteristics, p.e. a specific collision type. In this case, the accidents may have happened in a large area.

Routes are also investigated in France and Spain. As 'black routes' are regarded routes along which the accident rate is more than 2 to 2.5 x the average for that type of route. If so, an overall diagnosis of that route is made, a.o. on consistency.

* * *

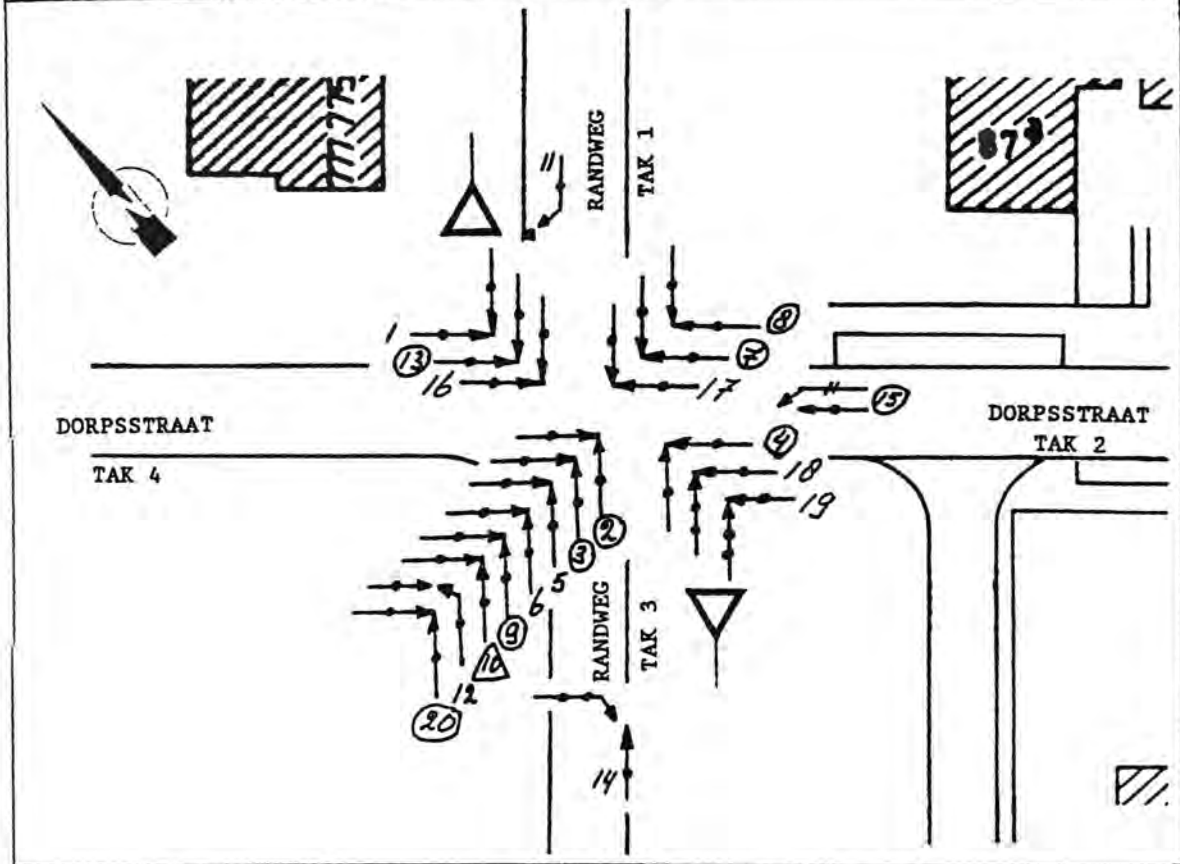

1. Data collection
2. Data analysis
3. Formulating the hypotheses
4. Hypothesis testing
hypothesis confirmed?
N
5. Additional investigation
Y
6. Establishing the accident causes
hypothesis confirmed?
Y
N
7. Proposing the countermeasures
End

AVOC 1a. Verzamelen gegevens

Manoeuvrediagram

Wegbeheerder: Gemeente Sluipoord

Locatie: Dorpsstraat / Randweg



verkeersdeelnemer		beweging	
- - - →	voetganger	——→	rechtdoor
—+—→	fiets	——→|	stilstaan
—╫—→	bromfiets	P→	parkeren
—⊖—→	motor/scooter	⇉	afslaan
—●—→	pers.auto	—⌒—→	inhalen
—●●—→	vrachtauto/bus	⊃	keren
—■—→	landb.voertuig	~~→	uit de koers raken, slippen
—□—→	bakfiets/handw en overige vtg	_/‾→	van rijstrook wisselen
⇒	tram/trein	←→	achteruit rijden
- -D- →	dier	?	plaats onbekend
●	los voorwerp		
■	vast voorwerp		

periode: 1988 t/m 1990

voorrang: ▽ ~~tijd: ...~~

intensiteiten 1988

Randweg

Dorpsstr.

2150 mvt/etm.

3160 mvt/etm

6	ongeval met u.m.s.
⑦	ongeval met letsel
⑧	ongeval met dodelijke afloop

aantal ongevallen: 20

met dodelijke afloop: 1

met letsel: 9

met u.m.s.: 10

Aanpak gevaarlijke situaties

AVOC 1b. Verzamelen gegevens

Ongevallenschema

Wegbeheerder: Gemeente Sluipoord Locatie: Dorpsstraat / Randweg

1. nummer ongeval	②	③	5	6	⑨	10	12	⑳	④	18	19	⑦	⑧	17	1	⑬	16	11	14	⑮
2. dag	Wo	Za	Za	Vr	Ma	Wo	Do	Zo	Do	Di	Di	Wo	Do	Vr	Vr	Zo	Do	Do	Vr	Wo
3. datum	1/8/88	14/8/88	23/10/88	29/10/88	23/5/89	8/6/89	15/9/89	30/12/90	19/8/83	29/9/90	23/10/90	28/4/89	13/1/89	25/5/90	7/5/88	22/10/89	9/2/90	1/9/89	28/10/83	16/11/89
4. tijdstip	22^{25}	15^{30}	14^{00}	14^{30}	15^{48}	21^{30}	9^{50}	11^{30}	16^{35}	9^{00}	8^{20}	11^{45}	23^{35}	17^{10}	20^{00}	13^{35}	7^{00}	14^{30}	12^{25}	19^{05}
5. aantal betrokken objecten	2	2	2	2	2	3	2	2	3	2	2	2	3	3	2	2	2	2	2	2
6. aantal slachtoffers	3G	1G	-	-	3G	1D	-	1G	1G	-	-	1G	1G	-	-	1G	-	-	-	1G
7. manoeuvreplaatje	→↑	→↑	→↑	→↑	→↑	→↑	→ ↖	→↑	↑←	↑←	↑←	↓←	↓←	↓←	→↓	→↓	→↓	■↙	↘ ↑	↙ ←
8. hoofdtoedracht	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	71	39	05
9. leeftijd 1e betrokkene	49	43	32	67	23	50	25	56	75	30	22	51	72	38	58	21	37	40	50	17
10. vervoerwijze 1e betrokkene	↑	↑	↑	↑	↑	↑	↰	↑	↑	↑	↑	↓	↓	↓	↓	↓	↓	↲	↘	↙
11. leeftijd 2e betrokkene	40	44	44	35	35	22	28	25	25	27	19	42	32	58	40	23	25	-	28	47
12. vervoerwijze 2e betrokkene	→	→	→	→	→	→	→	→	←	←	←	←	←	←	→	→	→	■	↑	←
13. lichtgesteldheid	Dui	Li	Li	Li	Li	Li	Li	Li	Li	Li	Li	Li	Dui	Li	Li	Li	Dui	Li	Li	Dui
14. weersgesteldheid	Dr	Dr	Re	Re	Dr	Dr	Re	Dr	Dr	Re	Re	Re	Dr	Dr	Dr	Dr	Dr	Re	Dr	Re
15. toestand wegdek	Dr	Dr	Na	Na	Dr	Dr	Na	Dr	Dr	Na	Na	Na	Vo	Dr	Dr	Dr	Na	Na	Dr	Na
16. alcohol	ja	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17. opmerkingen																				

Werkblad AVOC

OECD Workshop B3 on
INFRASTRUCTURE DESIGN AND ROAD SAFETY
Prague, Czech Republik, 15-18 November 1994

Low-cost engineering measures

Marinus (Pim) Slop
Prague, Czech Republik, 17 November 1994
SWOV Institute for Road Safety Research,
The Netherlands

Priority rating during a black spot analysis

It may be necessary to set priorities in various stages of a black spot analysis:

- in the selection phase: if many black spots are discovered
- if a choice must be made between various possible countermeasures on a location
- if the total cost of the countermeasures on all locations that have been investigated exceeds the available budget

Some usual rating methods:

1) Simply choose the countermeasures that are expected to reduce at most the number of accidents or injuries.

   But: these are usually also the most expensive!

2) Express the expected accident reduction in terms of money (per year): *benefit*.

   Then calculate the difference between this benefit and the *cost* of the countermeasures (per year, i.e. the investment divided over 30 or 40 years + interest, depending on the rate).

   Finally, choose the countermeasures that show the largest positive difference.

   But: expressing the accident reduction in money is arbitrary: only the costs of material damage and medical care? Or also the costs for society, also an equivalent for immaterial damage, etc?

3) Use the same basic values as in 2), but calculate the ratio, by dividing the benefit by the cost: this is what you get back for your investment each year.

4) Calculate the number of *injuries* to be saved by a countermeasure, per unit of money that is needed for this countermeasure: cost-effectiveness.

Tendency to use last method. A high cost-effectiveness (= low cost, high effectiveness) means that you get most safety for your money. This generally leads to the implementation of **low-cost measures**.

‘Low-cost’ is arbitrary, but following measures could be regarded as *examples* of low-cost safety measures:

Problem	Measures
Narrow lanes and/or shoulders	Pavement edge lines (m)
	Raised pavement markers (m)
	Post delineators (s)
Roadside obstacles or steep sideslopes	Roadside hazard marking (m)
	Guardrail (a)
Narrow bridge	Hazard marking (m)
	Pavement markers (m)
	Right of way control (s)
	Approach guardrail (a)
	Speed reducers (c)
Sharp horizontal curve	Post delineators (s)
	Obstacle removal (a)
	Pavement antiskid treatment (a)
	Obstacle shielding (a)
	Speed reducers (c)
	Shoulder widening (c)
	Appropriate superelevation (c)
	Gradual sideslopes (c)
Poor sight distance at crest	Post delineators to pre-show vertical alignment behind crest (s)
Various hazards at intersections	Priority control (s)
	Signal control (s)
	Pavement antiskid treatment (a)
	Public lighting (a)
	Speed reducers (c)

m = marking
s = signing and signalling
a = additional constructions
c = road constructions

N.B. (Horizontal) marking (on the spot!) has usually more psychological impact than (vertical) signing before you reach the dangerous spot.

Presented in this order, it is suggested that, generally, the upper measures are cheaper, each time. But, conditions may be different in every concrete situation. Moreover, not all low-cost measures will yield a high cost-effectiveness! At some places, low-cost measures won't work, while measures that are a bit more expensive will work excellently.

There is a need for not only a list, but a **catalogue** of all measures that can possibly serve, depending on the conditions in each situation, as a low-cost safety measure. This catalogue need not be identical for all countries, but could be concentrated on specific aspects of each country.

This catalogue should clearly present the various solutions. This may be done by drawings on which the essential elements of the measure are made clear by showing the before and the after situation. The drawings could be situation plans, as usual in traffic engineering, but designed in such a way that they can be understood by non-technical persons. This can be of benefit in trying to get sufficient base of support. Perspective drawings can be even better in this respect, but photographs of solutions applied in reality have disadvantages.

Books with examples of successful low-cost safety measures exist. But often you will experience that they show something different from what you are looking for.

For each measure, the following matters should also be systematically indicated:
- the possible fields of application
- dimensions with possible relaxations
- details of the construction
- recommended combinations with other measures
- positive and negative aspects (+ cost?)

Low-cost engineering measures may also be classified according to their degree of coercion:

A. measures of an *informative* nature: road users are alerted to the fact that a particular kind of behaviour is expected from them;
B. measures of a *suggestive* nature: road users are subconsciously urged to adopt a certain kind of behaviour;
C. measures of a *persuasive* nature: the road user is clearly persuaded to behave in a certain manner;
D. measures of an *obliging* nature: road users are legally obliged to behave in a certain manner;
E. measures of an *obstructive* nature: specific traffic behaviour is physically forced on the driver.

Examples:
A: warning signs, directional signposting
B: most markings and delineators
C: uneven road paving causing discomfort
D: priority signs and other compulsory signs
E: kerbstones preventing certain movements

In this order, increasing level of coercion.

A most important principle to avoid accidents and to reduce their seriousness is speed reduction. Application of the above classification on the implementation possibilities in the case of 30 km/h zoning:

A: Signs 'Please reduce speed' or advisory speed limit signs; their effect is expected to be too limited if applied alone.
B: Narrowing a lane or carriageway, either visually or physically.
C: Humps and other 'bumpy shapes'.
D. Compulsory speed limit signs; their effect is depending on compliance by the road users: no overwhelming effect to be expected without supporting measures B, C or E.
E. Forcing the driver to follow a specific course.
Creating a blocking mechanism caused by oncoming traffic (effect depending on traffic volume).

Effect may be reinforced by repetition or combination of measures.

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Vulnerable road users

Marinus (Pim) Slop
Prague, Czech Republik, 18 November 1994
SWOV Institute for Road Safety Research,
The Netherlands

Vulnerable road users

Improving their safety is part of road safety policy in many countries.

Who are vulnerable road users?

- those 'weaker' in accidents, influenced by differences in mass and degree of protection;
- those having a lower degree of physical resistance resulting in a higher risk of (serious) injury or fatality, p.e. elderly road users;
- those having poor abilities to behave correctly in traffic, because of lacking knowledge of traffic regulations, experience in traffic, speed of response, etc., p.e. children;
- those who cannot strictly be regarded as traffic participants, but who can nevertheless be a road victim, e.g. playing children or shoppers.

Other aspects: never to be blamed; not in a position to 'buy' more protection, etc.

Practical yardsticks for vulnerability:
- groups showing high accident risk per km travelled;
- party which is usually the injured one in a certain type of accident, e.g the bicyclist in a car/bicycle accident.

This leads to the identification of *pedestrians* (compared to vehicles), *bicyclists* (compared to motor vehicles) and *motorized two-wheelers* (compared to other motorized vehicles) as vulnerable road users, and within these groups particularly the young and elderly.

How are these groups incorporated in traffic? What can be done to improve their safety?

General principle: measures preventing the occurrance of accidents have preference over measures with a curative character.

Pedestrians compared to vehicles

Classic integration

The basic situation: all public space for all road users.
This is still the case on most rural roads, in small villages and in city centres with limited space. In principle, this is not a safe situation.

Segregation

Hazards call for segregation: vehicles on the carriageway, pedestrians on roadside pavements, protected by raised kerbs. Both categories use still the same road network.
This is the usual situation in towns nowadays.

Much safer, but still problems where pedestrians *cross*. There, the segregation ends each time.

Crossing pedestrians may occur:
- on links
- at junctions

Pedestrians don't have rights when they cross links, away from junctions. At junctions, pedestrians have no rights in relation to vehicles approaching crosswise, but they have right of way over turning vehicles (= vehicles that *have* turned). Priority signs have no influence.

The *legal* position of the pedestrians can be improved by:
- installing a zebra crossing
- signal control

On a zebra, pedestrians have right of way over all vehicles.
It should be noted that right of way is not identical to safety. In many cases, the situation may get worse. In general, a zebra *could* be favourable for pedestrian safety if it is:
- installed on a logical place
- clearly recognizable from a distance
- frequented by pedestrians and
- not located on a high volume road.

At a signal controlled crossing, possible conflicts between pedestrians and crosswise approaching vehicles are usually eliminated by red and green phases. (Variations: pelicans, toucans etc.)

Elimination of conflicts may also be the case in relation to turning vehicles if these have got a phase separate from the pedestrian phase. This requires a separate streaming lane for the turning vehicles. Especially in urban situations, this is often not effectuated, the reason being lack of space or the drop in junction capacity connected with this practice. Then, there is a common green phase for crossing pedestrians and turning vehicles, and the right of way situation between them is the same as at non-signalized junctions.

Not mentioned until now: the possibility of grade separated crossing.
This is, in principle, extremely safe; but very expensive, and effect may be disappointing if the facility is poorly used.

Zebras and traffic lights are facilities of a curative character; their safety effect is entirely depending on the compliance with the rules governing them. This goes for the pedestrians as well as for the drivers.

Additional safety measures of a more constructional character may be more effective, p.e.:
- pedestrian refuges
  -> a safe island between vehicles streams, and much shorter crossing times
- raised zebra
  -> forced speed reduction to vehicles

Segregation in advance

Separate networks for pedestrians and for vehicles.

3 basic forms:
- small-scale solutions, where the networks are topographically separated, p.e. pedestrian shopping areas in city centres, footways along short dwelling blocks; both with backside approach for vehicles;
- medium-scale solutions, where both networks overlap, but are constructed on different levels; otherwise, the level crossing problem remains; examples in larger city centres;
- large-scale solutions with overlapping networks at the same level, where only the crossings are grade separated; some examples in modern city quarters.

Modern integration

'Woonerf' -> back to original situation (no pavements), but with very low vehicle speeds only: 'walking pace'; equal rights for all road users. Successful introduction in the Netherlands starting in the 70s; implementation has decreased because of some practical problems and high cost.

Non-motorized compared to motorized vehicles

In practice predominantly: Cyclists compared to cars.

Although the number of cyclists may still be small in most CEE countries at this moment, there is reason to pay attention to these conflicts because a promotion of bicycle traffic is a matter of growing interest.

Classic integration

Again, the basic situation: all vehicles share the same road space. And again, the situation that is most found on our roads. Not safe.

Segregation

Cycle tracks, separated from carriageway.
Usual separation:
- in NL by separating verge > 1.5 m
- in DK by kerb.

Usual implementation:
- inside built-up areas: one-way track at both sides
- outside built-up areas: two-way track at one side.

On medium volume roads inside built-up areas also: cycle lanes (one-way).

Combined cyclist/pedestrian tracks along links not recommended.

Again, the situation on the links is usually safer, after tracks have been built. There is an exception for the places where cyclists cross links. This is particularly the case on rural roads with one-sided track, where cyclists want to reach the other side. (There is almost no good solution to this problem: signal control is not suitable, since signals are often being neglected under these conditions. -> Try to combine the cyclist crossing with another discontinuity or create it on a conspicuous spot.)

At the junctions (where segregation ends!), the safety situation is often worse after tracks have been built along the links.

- One-way track at both sides (usual on urban roads):

The right of way regulations are more complicated for the cyclists than for the pedestrians: cyclists have to do with other vehicles and also with pedestrians; and if priority signs are present another behaviour is obliged.

A major problem is the possible conflict between a straight on going cyclist and a turning motor vehicle from the same or the opposite direction. Motorists don't notice the cyclist on his own track. This is the main reason for the Danish practice of applying only a kerb between carriageway and cycle track. Sometimes, this kerb (or the verge) is even omitted over the last 20 or 30 m before a junction (a 'truncated' cycle track). The cyclist is better being noticed and the two road users can weave.

A similar problem occurs between a left turning cyclist and a straight on going motor vehicle from the same direction. The truncated track enables the cyclist to weave towards the left in time.

At signal controlled junctions, the cycle tracks are usually continued across the side road:
- separate signal heads
- preferable position of signals (protecting partly against right turning cars)
- separate phasing possible (but: capacity drop and longer waiting times causing disobedience!)
- indirect left turning for cyclists is safer

Here, a general problem arises: design must be accepted by cyclists!

With bicycle lanes, other ideas:
- advanced bicycle stopping line
- recessed stopping line for motor vehicles

- Two-way track at one side (usual on rural roads):

Main hazard at junctions is caused by cyclists coming from the 'wrong' direction who have priority. Possibility: bending out the cycle track, while obliging the cyclists to give way to the traffic from the side road.

Segregation in advance

Separate networks for cyclists and motor vehicles, with grade separated mutual crossings.
May be accomplished in new quarters.
In existing situations, this ideal can be replaced with a system using minor residential streets, away from traffic arteries, for the creation of a bicycle

network or, at least, as parallel routes. The problem of crossing the arteries remains by then.

Modern integration

This is aimed at in the concept of 30 km/h zoning. In such zones, motor vehicle speeds are low enough to allow cyclists to share the road space with them. At 30 km/h, there is usually enough time for reaction in case of an imminent collision; and if a collision occurs the consequences are mostly not serious. 30 km/h zones are popular nowadays.

Motorized two-wheelers compared to other motor vehicles

In practice predominantly: Mopeds compared to cars.

No ‘classic’ situation here. Mopeds were initially seen as bicycles with auxiliary motor, and treated accordingly, also legally, p.e. obliged to follow the cycle track if present.
But mopeds look and behave more and more like motorcycles. In many urban situations, their speed is equal to that of the cars, sometimes even higher. They started to become a nuisance and a hazard on the bicycle facilities. And accidents involving mopeds occurred relatively often at the junctions where the cycle tracks end.
In recent years, there have been succussful experiments where mopeds were relegated from the cycle track to the carriageway.

Road signs, markings and working zones

by Kenneth Kjemtrup, The Danish Road Directorate

Background

This memorandum reviews the fundamental principles of planning, establishing and maintaining road signs, so that they can be seen and understood at all times by road users.

These principles are treated in such a way that they apply across the entire spectrum of traffic culture and national borders. No position has been adopted on the use and design of road markings other than that which is necessary for road users to be able to read and understand the information given.

This paper treats vertical signs, road markings and the marking of road work zones.

1. Vertical signs

Purpose

The purpose of erecting **directional signs** is to guide road users or to control traffic. One condition for attaining this goal is that road users can find the directional signs and that they can read the information on them.

The purpose of erecting **traffic signs** is to prohibit, warn, command or guide road users. There can be a risk of fatalities if road users cannot see "give way" signs sufficiently early or if they cannot read or understand pictograms and symbols.

It is vital that signs can be seen and read throughout their life cycles. The conditions for this are described in the following.

1.1 Read and understand information when travelling in daylight and by headlight illumination

As far as the reading and understanding of information is concerned, road users' needs can be divided into four phases:

a. observation of information
b. selection of information
c. reading and processing of information
d. braking distance.

Observation of information

The observability of a sign depends on its location, the prevailing lighting conditions and the size of the sign.

Location, general

We know that the field of vision is narrow at high speeds and that it is broader at low speeds. However, this does not mean that, where speeds are low, we can locate information far from the roadside, within the field of vision. Where speeds are low there is usually a traffic situation that also demands the attention of road users.

Information shall be located uniformly in the cross section of the road so that road users do not need to search for it.

Location of directional signs

Arrow directional signs shall be located in the most remote left-hand corner for road users turning left, and in the nearest right-hand corner for road users turning right. These choices of location are due to the fact that vehicles that must give way must not obscure this information.

When there are several items of information, the most important information must be located closest to the junction.

It is vital to locate signs as close to junctions as possible, so that road users can see the information without stopping. It is often the case that directional signs are located altogether too late in the phase of designing a junction, so that the location of signs, instead of being optimum, becomes more an exercise that stretches to the limits of human ingenuity. It is important to perceive directional signs as integrated parts of road projects. If a directional sign cannot be seen we might just as well not erect it. Although accident statistics do not support it, there appears to be no doubt that signs that only become visible at the last minute do entail a great risk of accident for road users. As early as the pilot project, the rules governing the design of roads should give consideration to the information given on signs, and their optimum location for timely visibility.

Out of consideration for grass and snow, the lower edge should be at least 0.5 m above the ground and, where there is a free-sight area, the height of the upper edge should be not more than 0.9 m, including the scaffold, as measured from the road surface.

If directional signs must be erected in the free-sight area to ensure that they can be seen, and if there are several items of information that cannot be placed on a single line, consideration should be given to replacing the arrow directional signs by a stack direction sign. If this proves impossible arrow directional signs can, under exceptional circumstances, be erected on a high post, so that the height of the lower edge is a minimum of 1.25 m and a maximum of 2.80 m. A check must be made to ensure that truck drivers (eye height: about 2.5 m) can either see over or under the sign.

Stack direction signs shall be located to the right of the road, normally about 25 to 50 m before the junction. Their height shall be the same as that of high arrow directional signs.

Gantry signs shall be erected so that there is no doubt as to where road users shall position themselves in order to continue in the desired direction. They should normally be located before the junction.

Other advance direction signs shall always be erected to the right, between 100 and 150 m before the junction outside densely populated areas, and at least 50 m before the junction in densely populated areas.

The distance from the lower edge to the edge of the road shall be a minimum of 1.0 m and a maximum of 2.8 m: in all other respects as for high arrow directional signs. The distance from the edge of the road to the closest edge of the sign is normally 1.5 m.

Location of traffic signs

In the road cross section, the distance from the nearest edge of a sign to the edge of the road shall be greater than 0.5m and the distance from the edge of the lane to sign posts shall be less than 4.5 m.

Signs are normally erected so that the lower edge of the primary sign is 2.2 m above the edge of the road surface. The height of the lower edge must not be more than 2.8 m and, out of consideration for grass and snow, not less than 0.5 m.

Signs must not be erected so that they are obscured by parked vehicles or suchlike, so that road safety is impaired.

Neither must the view of other road users be obscured by signs, such as signs located in the central strip at junctions, so that left-turning road users' view of on-coming traffic is obscured.

The following signs can be erected at heights of below 1.5 m:
(The sign numbers refer to the ECE European Road Traffic Rules.)

On motorways:
- none

On heavily-trafficked roads:
D,2, E,9^{a} and E,9^{b}

On other roads:
A,29 and A,6

All prohibition signs except:
C,7, C,8, C,6, C,13, C,14 and C,17

All mandatory signs except:
D,1, D,7 and D,8

All advisory signs except:
E,11^{a}, E,15, E,16, E,17 and E,18

In the case of signs used at road works, the height of the lower edge must not be less than 1 m.

Traffic signs are normally located on the right-hand side of the road, and are occasionally supplemented with signs on the left-hand side or over the road.

However, the following signs are normally located on the left-hand side or at the tips of middle islands in the road:

C,7, C,11^{a}, C12
D,1^{a}, D,2
E,13

Signs are normally erected along the road in their order of precedence, as follows.

- Warning signs - normally 150 to 250 m before the site of the hazard, depending on driving speed

- Give-way signs - a maximum of 20 m from the point at which they apply, unless they are used as a warning.

- Prohibition signs - from the point at which they apply, unless otherwise stated on a supplementary sign.

- Mandatory signs - from the point at which they apply.

- Advisory Signs - from the point at which their content applies.

At junctions, traffic signs shall be located so that turning road users can see them sufficiently early to abort a turn without inconveniencing other road users. This often means that a sign must be supplemented, rotated (by up to 15°) or angled.

Lighting conditions

Daylight: there is normally no difficulty in viewing correctly-located directional signs or traffic signs. A arrow directional sign with a height of 33 cm can be seen at a distance of 220 m and at a speed of 80 km/h, this corresponds to a period of visibility of about 10 seconds for the road user.

Headlight illumination: when the headlights are dipped the observation distance also depends on signs' reflection of the headlights and their location in the road cross section. The location of reflecting signs is of great importance to their visibility.

We distinguish between three types of reflecting sign material:

type 2: diffusely reflecting
type 3: retro-reflecting
type 4: strongly retro-reflecting.

Type 2 reflects only an insignificant part of headlight illumination and therefore appears to be black.

Types 3 and 4 reflect headlight illumination more concentratedly, so that signs are bright and colours can be recognised.

Type 4 reflects at a considerable distance, more strongly than type 3, and can therefore be seen at a greater distance.

When performing extensive illumination calculations, which are checked by observations in the field, studies in Denmark have been conducted to determine which type of retro-reflection is necessary for observation of the various directional signs and traffic signs, when they are located at the most unfavourable location in the cross section.

A 33 cm high arrow directional sign erected low on the left can be obscured at a distance of about 100 m for a type 3 sign, and about 130 m for type 4. This corresponds to a period of visibility of 5 and 6 seconds, respectively, at a speed of 80 km/h.

Observation angle, α	Entrance angle, ß	White	Yel-low	Orange	Red	Green	Blue
0.33°	5°	180	122	65	25	21	14
2°	30°	2.5	1.5	0.8	0.4	0.3	0.1

Table 1. Minimum values for retro-reflectance, expressed as $(cd/lx)/m^2$ for type 4 sign material.

Observation angle. α	Entrance angle, ß	White	Yel-low	Orange	Red	Green	Blue
0.33°	5°	50	35	20	10	7	2
2°	30°	2.5	1.5	0.8	0.4	0.3	0.1

Table 2. Minimum values for retro-reflectance, expressed as $(cd/lx)/m^2$ for type 3 sign material.

All traffic signs of reduced size (about 40 cm) can be seen at a distance of about 150 m, when using the weakest type 3 retro-reflectionsheet.

Obviously, it is vital that the signs be as nearly perpendicular to the direction of travel as possible.

However. considerations of specularity dictate that they should be rotated 3-5° away from the normal to the direction of driving.

Selection of information

To reduce the reading time. it is important to organise the information in logical groups which, with a simple code. indicate the type of information on each sign. The simplest types of code available are colour coding or form coding.

In the case of directional signs, colour coding according to the following scheme is often used:

- * directional signs on motorways (green or blue ground)
- * directional signs in the ordinary road network
  - to towns or terminals (national colour)
  - to service destinations (national colour)
  - tourist information (brown ground)
- * directional signs for path users (national colour)
- * temporary directional signs (yellow or orange).

When we speak of observation of a traffic sign, it is the figure - a triangle, a circle with red edge, a blue circle or a square - that is observed. Because of the predominantly white background of most signs, there is little to be gained from the standpoint of the form-observability distance by using type 4 retroreflectionsheet. The sign will merely show up as a bright spot.

Signs with differing forms should not be erected back-to-back. When, under exceptional circumstance, this must be done, the significance of the front of the sign shall be absolutely apparent.

By organising the information in accordance with a simple code, a road user can distinguish the desired information before it is possible, or necessary, to be able to read the information. Therefore, it is important that the highway authorities maintain strict discipline from the standpoints of coding and information type. If this is not done, road users will either be confused or will spend precious time on reading information for which they have no use.

Reading and processing of information

First and foremost, there must not be more information than a road user can read at the prevailing speed. The reading of information distracts the driver's attention from driving and from other road users, for which reason the time required must not be longer than is absolutely necessary. Traffic psychologists all over the world agree that road users should not be presented with more than 4 items of information (words of average length) during the 2-3 seconds for which it is permissible to distract their attention. At a driving speed of 80 km/h, this corresponds to a driving distance of between 50 and 70 m.

In the second place, the information must be legible, ie it must be possible to read the text over the entire reading distance. Once again, the luminance of the sign, speed of the vehicle and location of the sign in the cross section are all of significance.

In the case of directional signs, the style and size of the text are significant. In the case of traffic signs, the size of the symbol and the luminance of the sign's surroundings are significant.

In urban areas, there is a pronounced degree of luminance competition between traffic signs, on the one hand, and, in particular, advertisements, on the other. Traffic signs cannot win this competition by switching from type 3 retroreflection to type 4. This problem can only be solved through a prohibition against illuminated advertisements that can make difficult the perception of the relatively small traffic signs. Traffic signs could possibly be illuminated and enlarged, but this would be detrimental to the urban environment.

Against the background of T. W. Forbes' legibility formula - the only dynamic legibility formula in existence - the relationships can be calculated between text size/symbol size, location of information in the cross section, reflector type (3, 4 or illuminated) and driving speed.

Directional signs

The situation under headlight illumination determines the choice of text size. The heights and sizes are as follows:

* On roads with speed limits of below 80 km/h and at T-junctions:

  H < 2.2 m to lower edge of text: 143 mm height of capitals, with type 3 reflector

  H ≥ 2.2 m to lower edge of text: 170 mm height of capitals, with type 3 reflector

* On roads with speed limits greater than or equal to 80 km/h, but less than or equal to 100 km/h:

  H < 2.2 m to lower edge of text: 170 mm height of capitals, with type 3 reflector

  H ≥ 2.2 m to lower edge of text: 202 mm height of capitals, with type 3 reflector.
  or
  170 mm height of capitals, with type 4 reflector.

* On gantry signs outside motorways:

  240 mm height of capitals with type 4 reflector, regardless of illumination.

* On motorways:

  285 mm minimum height of capitals with type 4 reflector.

* On directional signs on paths:

  60 mm maximum height of capitals with type 2 reflector.

Traffic signs

The basis for using T. W. Forbes' legibility formula is the "Helvetica" typeface. In the case of traffic signs carrying symbols, it is therefore necessary in calculations to equate symbol sizes with text sizes.

Because of the risk of confusion in stores, it is necessary to specify a minimum type of reflector for each type of traffic sign.

A table has been produced in Denmark, showing as a function of driving speed the symbol size (and therefore the sign size) that should be used, for a given type of reflector and its location in the cross section of the road.

In the case of VMS signs, it can often be difficult for the fields of light points to display pictograms and characters that are sufficiently similar to the pictograms and characters of conventional signs. Research into this problem - which is especially conspicuous in matrix signs - is being conducted all over the world, and great care should be taken in the use of this technology until there is a satisfactory solution.

Braking distance

Directional signs

There shall be sufficient space for braking from the point at which drivers' processing of information ceases. It is normal to expect braking down to 20 km/h before turning at junctions.

At junctions on ordinary roads where the prevailing speed is 80 km/h or above, where there are only arrow directional signs and no advance direction signs or stack direction signs, it can be difficult to attain a sufficiently long reading distance + braking distance for traffic turning left. This problem can be solved by:

1. reducing the amount of information, which reduces the reading distance needed;

2. increasing the height of characters to 202 mm;

3. establishing local speed limits at junctions, eg 70 km/h;

4. warning drivers with an advance direction sign;

5. using stack direction signs.

Traffic signs

Obviously, there must be sufficient room for braking before arriving at signs that prohibit road users from continuing or that command them to give way or change direction.

1.2 Operation and maintenance of signs

Signs shall be legible throughout their life cycles.

Any grass shall be clipped, snow shall be removed to prevent it from drifting over the sign, and signs shall be replaced or renovated when they become illegible.

When is a sign illegible?

- when its retro-reflectance has dropped to less than 70% of its required value when new (see Tables 1 and 2)
- when the relation between the greatest and least retro-reflectance within the same area has dropped to less than 0.5
- when its colours are no longer within the colour limits specified in the colour triangle
- when there is significant damage to the sheet
- when the colours have become faded.

1.3 Design of vertical signs

Vertical signs shall be dimensioned for relevant dynamic loads (wind and snow) and for static loads (weight of sign, etc.). This dimensioning can be performed by calculation.

Road signs, eg with tube dimensions of greater than 80 mm, should either be protected by guard rails or be equipped with break-away safety devices, where driving speeds exceed 50 km/h. Accident statistics from all over the world show that drivers run a grave risk of being killed if they collide with robust sign posts.

2. Road markings

Purpose The purpose of marking roads is to guide, advise and regulate traffic with a view to increasing road safety and the effective flow of traffic. Road markings shall therefore be visible under all conditions of illumination and, to the extent possible, under all weather conditions. Obviously, markings cannot be seen if the road surface is covered with snow or dirt to any significant extent, and they can be difficult to recognise in wet weather. However, some types of marking are more visible than others in wet weather. Their visibility also depends on their length and width. Finally, the visibility of markings also varies according to the season in regions where dew occurs.

Types of road marking

There are the following three types:

- flat markings
- profiled markings
- studs

Flat markings: all markings on roads where no special structuring of the surface has been carried out. Flat markings can comprise painted markings. thermoplastic, cold plastic or tapes.

Profiled markings: all markings on roads where there is special structuring of the surface to ensure that rain water drains away. Profiled markings can comprise thermoplastic, cold plastic or tapes.

Studs: special devices attached to the road surface. They are fitted with especially powerful reflectors.

Visibility under varying conditions of illumination and weather

Daylight, dry road surface

Markings are sufficiently visible in dry weather and under daylight if their reflectance is higher than that of the road surface. Reflectance in daylight is specified at the average luminance coefficient, Q. The road's Q is normally not greater than 0.09 cd/m^2/lux

There is normally no difficulty in attaining a greater average luminance coefficient for road markings.

Their reflecting capability when backlit (ie when traffic is driving towards the sun) is called the "specular factor". S. Their specular factor shall be greater that 0.3. and. as no profiled marking can attain this figure. such markings appear dark when backlit.

Street lighting, dry road surface

The same conditions apply here as apply in daylight. except that backlighting causes no problem.

Headlight illumination, dry road surface

The visibility of road markings when illuminated by headlights can be significantly improved by mixing reflecting beads in the paint or mass used for road markings. If positioning of the beads is optimum, with the largest possible free glass surface towards the motorist and the greatest possible mass background away from the motorist, headlight reflection will also be optimum. This reflection is known as the "specific luminance", S_L, and is measured in mcd/m^2/lux.

Road users can see markings at a sufficient distance if $S_L > 80$ mcd/m^2/lux.

Tests with road markings have shown that, on the average, the reflecting capability of profiled markings is better than that of flat markings when both types are new and after 4 years. This is due to the reflection contribution of the beads on the vertical surface. Thus, they function as the reflecting beads on sign sheets.

Tests have also shown that the reflecting capability drops sharply during the first year - to about half - after which the value becomes stable for as long as there is any remaining marking mass.

This sharp drop is probably due to the fact that the drop on beads disappear during the first year, after which the less densely-distributed beads mixed in the mass come to the front.

The luminance of new flat white markings should be greater than 160 mcd/m^2/lux and, for white profiled markings, greater that 200 mcd/m^2/lux.

Daylight and street lighting, wet road surface

The reflection of a marking becomes more diffuse when the road surface is wet, but not as much as that of the road surface itself. This means that the contrast increases and markings become more visible in most cases. However, this does not apply in conditions of backlighting. In such conditions there is a risk that markings will reflect more that the road surface when wet, in which case they can become almost invisible.

Headlight illumination, wet road surface

A flat marking cannot normally be seen by headlight illumination on a wet road surface because a film of water covers the marking. The light from the headlights is not reflected back to the driver.

A profiled marking can usually be seen because of the "vertical" beads and because the water from the road does not flow across the mass of the marking, but in between. If a profiled marking is to be seen as clearly in wet weather as in dry, the S_L must be at least 50 mcd/m^2/lux.

Studs are usually visible in wet weather, provided that they are not completely covered by water. The requirement on reflection is known as the coefficient of luminous intensity, R, which is measured in the same way as for traffic signs. R shall be greater than 5 mcd/lux.

Winter visibility by headlight illumination, dry road surface

Measurements on the Northern European test stretches show a sharp drop in the S_L value in the winter period, from October to February, after which the S_L value rises again during March-April, but not to the same level as the value when new - for the reasons explained above.

This drop is not due to the temperature or to dirt, but probably to dew. Dew drops are smaller than the reflecting beads and therefore give a diffuse reflection.

Visibility distance

"The necessary visibility distance is internationally defined as the time that enables the road user to drive a vehicle in an efficient and foresighted manner."

For give-way road markings, the rule is that the sign shall be visible from the stopping distance at the prevailing speed. The stopping distance at 80 km/h is 120 m and, at 50 km/h, it is 55 m. At 80 km/h, transverse road markings cannot be seen at the required distance, for which reason they are always supplemented with vertical signs. On the other hand, it is possible to see give-way lines at a distance of 55 m.

For longitudinal road markings, road users should have a visibility distance that corresponds to about 3 seconds. This corresponds to about 65 m, at a speed of 80 km/h, and about 45 m, at 50 km/h.

The visibility distance of an individual road marking depends on its location, width and prevailing light conditions.

In daylight and under street lighting, there is normally no difficulty in attaining a sufficient visibility distance, geometric parameters permitting.

In headlight illumination, conditions are otherwise.

A edge line that shall be visible at a distance of 65 m, and that has a specific luminance of 100 mcd/m²/lux shall, according to Fig. 1. be 30 cm wide if road users are to see it in time.

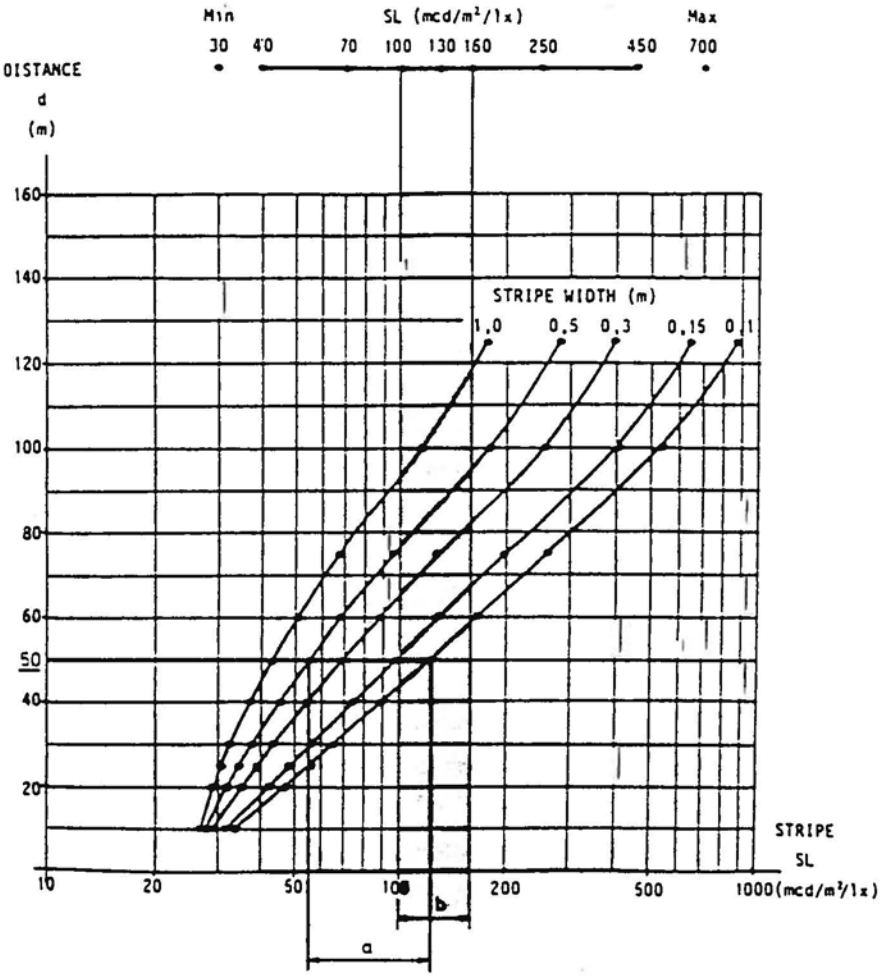

Fig. 1. Connection between visibility distance of a road stripe and its retroreflection.
a: Minimum specific luminance to obtain visibility distance of 50 m when the stripe is placed in the right side of the road.
b: Interval of specific luminance in GNC January 1983.

Centre lines are covered by Fig. 2. as it should be remembered that there are often two centre lines where sight is poor or where there are obstructions on the road

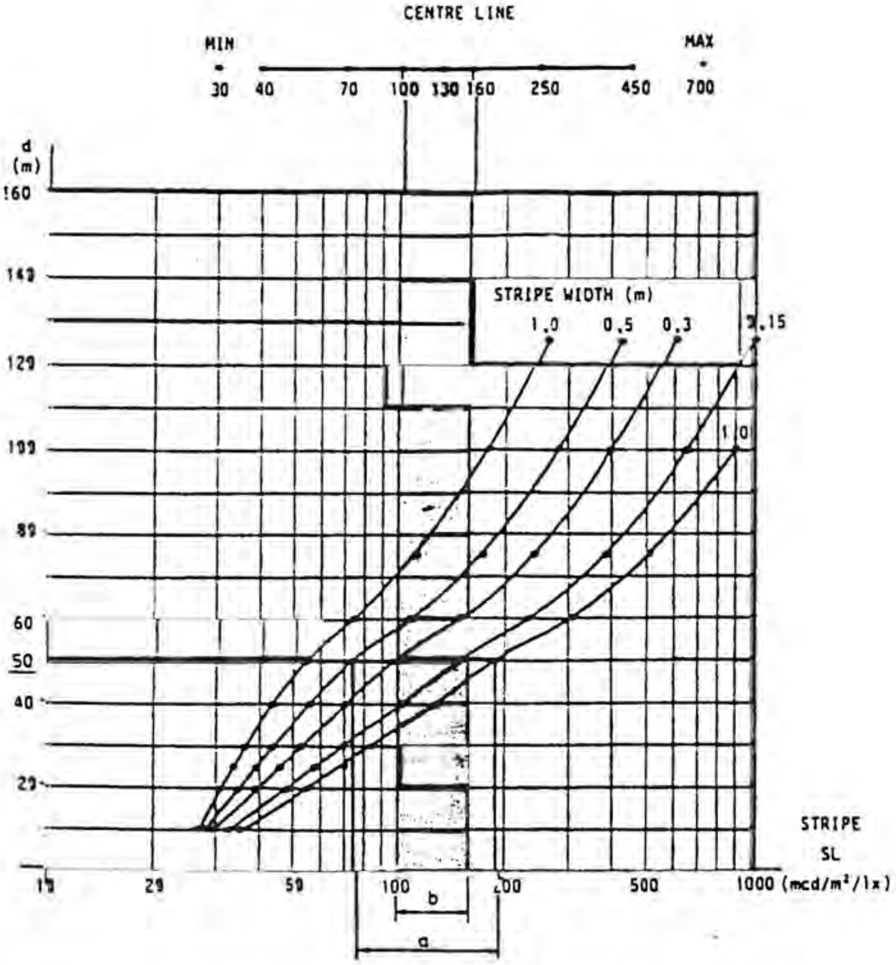

Fig. 2 . Connection between visibility distance of a road stripe and its retroreflection.
a: Minimum specific luminance to obtain visibility distance of 50 m when the stripe is placed in the middle of the road.
b: Interval of specific luminance in GWC January 1983.

If it is necessary to follow a centre line on a road where the prevailing speed is 80 km/h, the S_L of a single line should be about 400 mcd/m²/lux. or about 250 mcd/m²/lux. for a double line.

No known types of line can satisfy these requirements for very long, but neither is that necessary. German and American behaviour studies have shown that road users use the edge line when driving after dark - for very sound reasons. cf Figs. 1 and 2.

Colours of road markings

The following colours are used:

- white. for permanent markings
- yellow. for temporary markings or for marking kerbstones that extend a prohibition.

As yellow markings are more important than white. and take precedence over white lines. it is vital that the yellow colour should appear as yellow.

The colour coordinates of road markings are specified in the forthcoming European Standard, "Performance requirements for road marking materials".

Optimum use of the various types of marking

Road marking with and without reflectors

Reflecting beads should be used with yellow road markings for temporary traffic regulation and for all markings on unlit roads.

White markings with reflecting beads should be used on unlit roads and roads where the lighting is reduced.

All other markings can be used with or without reflecting beads.

Flat and profiled markings

Profiled markings, which are accompanied by audible noise, can be used for edge lines and painted islands, for yellow markings for temporary regulation and for yellow markings concerning stopping and parking.

In the case of these types of marking, the audible noise generated by a vehicle's wheels is advantageous to the driver of the vehicle. Drivers that have fallen asleep are awakened when they drive over such markings.

All other road markings, including edge lines along stretches where dwellings are located nearby, should be implemented as flat markings or profiled markings that are not accompanied by irritating audible noise.

Flat road markings shall offer sufficient friction out of consideration for two-wheeled vehicles. The coefficient of friction should be greater than 55 SRT units as measured with an SRT tester.

Road markings of short-term and long-term durability

Road markings of short-term durability can be used in places where they are not exposed to significant wear from vehicular traffic and for yellow markings for temporary regulation, eg at road work zones.

Studs

Studs are often used in road work zones, but they can also be used to supplement permanent road markings. In such cases, it is vital that the distance between the studs be chosen so that the line type (continuous or broken) is absolutely apparent.

Renewal of road markings

Road markings should be repaired or renewed when they no longer function satisfactorily.

- Road markings shall be functionally whole.
- The S_L value must not be less than 40% of the value when new and should be at least 80 mcd/m^2/lux.

3. Road work zones

Road work zones disturb the free passage of traffic and will therefore always be considered an inconvenience by road users.

A road work zone often comprises an obstruction of the road (a road worker, a road block, a hole or suchlike), with which there can easily be a collision if it is overlooked by road users.

And, last but not least, the formation of queues in connection with road work zones also comprises an accident risk.

It is therefore vital that road work zones be planned thoroughly and with the greatest possible consideration for the safety of road users, for passability and, obviously, with consideration for the people working on the road.

A plan that describes the potential for disturbance of traffic through a reduction in speed, and the probability of queue formation, should be drafted for every road work zone. A marking plan should also be drafted, showing clearly how disturbance potential can be minimised during the various phases of the work in progress, the marking materials to be used and the order in which they should be used, with a view to making the working area show up clearly and to inform road users of what lies ahead and how they should behave.

The decisive factor is reduction of speed to the level that is deemed suitable for the road users, themselves, and for the people working on the road. In places where road users do not respect speed limits, speed-reducing bumps can be laid out to give the desired speed reduction. For example, if road users are to stop at a red light, care shall be taken to ensure that they are informed of this in time and that they understand that they must stop.

If road users must change direction, they shall be given timely warning and understand what is expected of them.

Therefore, markings shall be observable, easily understood and unambiguous.

Although there are many different ways of marking road work zones in Europe, they have one thing in common - that the order in which traffic signs are set up follows the pattern "what to do", "why" and with speed reduction before information on changes of direction.

Apart from traffic and information signs, flashing yellow lights are often used, either as an attention flash or in a line, to form a guiding line.

It is well to remember here that attention flash lights can be glaring in the dark, for which reason it is appropriate to use equipment that reduces the illumination at night. A luminous intensity of over 500 cd entails a risk of disability glare in dark surroundings.

Traffic signs and other road equipment shall be located with consideration for cyclists - ie not on cycle paths - and shall be stable under all normal dynamic loads.

If temporary markings are laid out on the road, care must be taken to ensure that they are visible in all weather and lighting conditions and that they are significantly more visible than any permanent markings. In the case of road works of long duration, the permanent road markings should be removed.

In the case of diversions, the permanent directional signs that no longer apply shall be crossed out and replaced on the same sign with the temporary directional signs.

Finally, road equipment used at road work zones must not comprise a hazard to road users or others travelling on the road in the event of a collision.

Road markings at road work zones shall be removed when the work has been completed or when they no longer serve any purpose.