Road design, human behaviour and road accidents: towards a 'learning design community'

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Fred Wegman
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SWOV Institute for Road Safety Research, The Netherlands

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SWOV Institute for Road Safety Research
P.O. Box 1090
2260 BB Leidschendam
The Netherlands
Telephone 31703209323
Telefax 31703201261

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1. Sisyphus and the rock

In Greek mythology, Sisyphus was a legendary king who rebelled against the gods and was then condemned in the underworld to push a huge rock up a hill for all eternity. As soon as he reached the top of the hill, the rock rolled down to the bottom again. His name has become a synonym for endless hard labour which never achieves its goal.

The parallels with this tragic figure inevitably spring to mind when one is thinking and writing about the relationship between (geometric) road design, human behaviour in traffic and road accidents today. Over and over again, individual researchers try to inch the rock of 'road design, human behaviour and road accidents' a little higher. And although there are some successes in individual cases, researchers do not seem to be prepared to join forces in order to push one and the same rock uphill together. Each one is busy rolling his own rock up the hill. Worse still, some of them add an extra load to the rocks of other researchers, or distract Sisyphus from his onerous task. Why are so many people so anxious to be a Sisyphus? And why do the gods allow it?

There are still a substantial number of unsolved problems in the field of road design (i.e. geometric design), human behaviour and road safety, even though researchers and road designers have been working on the issue for decades. The design principles for a safe road network have actually been known for as long as roads have been designed. These principles can be briefly summarised in terms of (i) *functional use* of a road network (avoidance of unintended use of the road infrastructure), (ii) *homogeneous use* (avoidance of large variations in speed, direction and mass with moderate and high driving speeds) and (iii) predictable use (avoidance of uncertainties and errors by road users).

Accident risks are higher where these principles are not applied, or are applied less effectively. This is shown, for example, by a comparison of the risks (number of accident casualties per million motor vehicle kilometres) for various road types in the Netherlands (*Figure 1*). Where existing roads primarily serve a traffic or through function (ensuring efficient traffic movement), they must be relieved of the distributor function (serving districts and regions) and the access function (access to destinations along roads and streets). Motorways are monofunctional: they serve a traffic function only. Streets with a 30 km per hour speed limit also have a single function: an access function only. Both types of road carry relatively low risks. Road safety problems arise primarily when roads and streets have to serve different functions at the same time, and where road design does not correspond with road function: arterial roads within urban areas and single-lane roads outside urban areas.

The application of the above design principles leads to a functional and hierarchically developed road network (OECD, 1979 and Brindle, 1984). The Radburn principle was developed in the US (New Jersey) for residential areas as long ago as the 1920s, and was further elaborated during the 1950s and 1960s, for example in Sweden, in the 'SCAFT' guidelines.

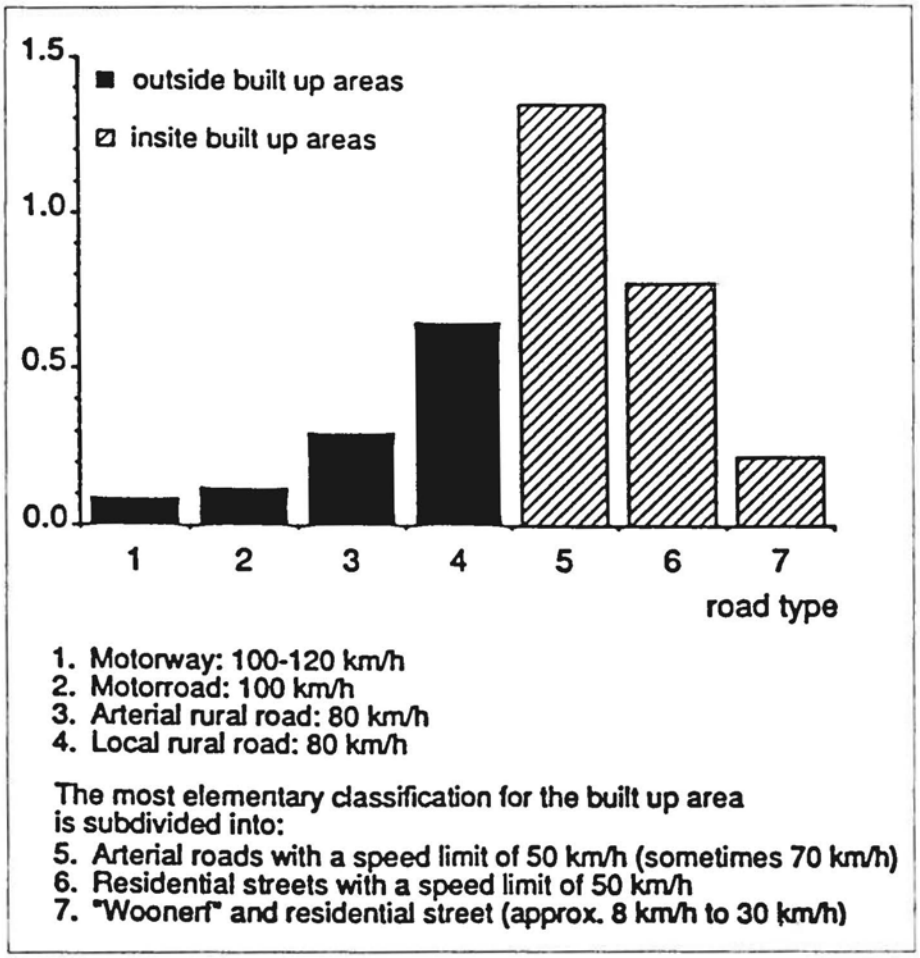

Figure 1. *Injury rates in The Netherlands (1986) per million motor vehicle kilometres.*

Design for road safety also played an important role in the development of a number of British new towns (e.g. Stevenage and Cumbernauld).

The so-called Buchanan Report, 'Traffic in Towns', describing how urban planners and traffic engineers should deal with traffic, appeared in 1964. Later, the concept of a rigorous segregation of traffic types was applied in the Netherlands (Amsterdam Zuid-Oost) and elsewhere, and the integration concept ('woonerf') was developed (residential areas designed to slow down traffic). The concept of traffic calming is now applied in a very large number of countries worldwide. Road safety considerations have also often played an important role in the design and redesign of city centres and in the reduction of motorized traffic. Finally, it can be noted that a great deal of information on the design of safe motorways is available in design guidelines.

However, it seems that the operationalisation of these design principles for existing road networks (apart from motorways and 'traffic calming' areas) is still largely virgin territory. What exactly is 'functional' use, what does 'homogenizing' of traffic flows mean and what do road users regard as 'predictable' in terms of the road's course and the behaviour of other road users? An additional problem here is the fact that these questions cannot be

answered through interpretation and comparison of design guidelines for roads and streets in different countries (Ruyters et al., 1994). This is because existing guidelines more often neglect a lack of knowledge in this area rather than explicitly recording it. This is understandable in view of the nature of design guidelines and recommendations, but it also restricts attempts to improve the quality of such documents and to provide support for their contents.

Answers to the following questions are therefore urgently needed:

- How can the above design principles be applied in existing circumstances? Will watering down the principles lead to a loss of quality in road safety, and to what extent will this be the case in specific circumstances?
- How can the above principles be operationalised in terms of concrete road design, and what departures from design guidelines are acceptable from the point of view of road safety?

2. The phenomenon of road safety

2.1. Road accidents described and explained

In describing road accident trends and explaining developments in this area, it is useful to distinguish between levels of aggregation.For example, a study of overall road safety in a country or region at the macro level, of a relatively homogeneous cross-section of the problem at the meso level (road types, types of traffic participants, types of vehicles, conditions, etc.) and at the lowest level of aggregation (the micro level), at the accident level.

A very basic problem for road safety is that road accidents - the subject of research and of policy - are difficult if not impossible to study, simply because they are rarely, if ever, actually observed and, in practical terms, cannot be observed, or only to a very limited extent. For this reason, the discipline has been very intensively involved from the start with accident reconstruction and statistical research based on data obtained after the event, mainly by the police. This means that we are dependent on indirect information, and sometimes also on biased information.

An additional and substantial problem is that police records have their flaws. The less serious the outcome of the accident, the greater the shortcomings in police reports (see e.g. Hauer & Hakkert, 1988). Attempts to study substitutions (traffic conflicts) rather than accidents themselves have also had little success so far. This shaky basis makes it more difficult to answer questions such as those presented in the introduction.

A second problem is the fact that consensus on the occurrence of road accidents and the best ways to avoid them would appear to be impossible. In fact, although different models have been developed to explain behaviour in traffic (Näätänen & Summala, Wilde, Fuller and Adams, Evans to name but a few), scientific discussions to date have not led to any acceptance of particular models in the research world. Presentation of the models has led to controversial outcomes rather than forming a basis for consensus. No reflection of these models for behaviour in traffic can therefore be found in guidelines for road design.

This is due partly to the fact that no 'road safety theory' exists, nor is there any tradition which would ultimately lead naturally to such a theory. Researchers often focus on very specific and, therefore, limited issues and we have the impression that these issues cannot really be placed in the broader context of a theory. This observation probably helps to explain the lack of progress in the field in recent times.

This means that our understanding of the micro level is certainly not adequate, and interest in this type of study among research financiers cannot be described as high. We recommend that this type of research receives more attention than is the case at present. The potential contributions of road design, as a contributory factor in the occurrence or prevention of accidents, should also be considered here.

A rich source of information has become available at the meso level. The risks for each road category and the factors which contribute to an increase or reduction in accident risk etc. are fairly well-known. Over the years, this field has enjoyed considerable interest from the research community.

Examples include studies that describe and explain the (higher) risks for young and inexperienced road users, the risks of drinking and driving and studies into the relationship between certain road design features and accident risks (TRB, 1987 and O'Cinneide & Murphy, 1994). But the harvest is certainly meagre if we want to translate functional, homogeneous and predictable use in terms of road design.

Over the years, a considerable body of knowledge has grown up on the scale and nature of road accidents at the highest level of aggregation. Well-known examples are the so-called macro models, which relate risk indicators and a variety of variables, such as mobility trends (AAP, 1991). But with our present level of knowledge, we are still far from being able to explain changes in traffic risks on the basis of our understanding of the accident process. Some successful attempts have been made in this area (Cameron et al., 1994), but this success is closely related to the scale of changes and interventions. Obviously, there are indications and expectations, but no conclusive explanations can be given as yet.

An example of the caution required on this point can be found in the attempts made to explain developments in road fatalities partly on the basis of economic indicators, in addition to the explanation based on typical road safety measures such as the introduction of speed limits (Partyka, 1991). The result of her studies was that a good description of developments in road fatalities over 22 years was found, but when seven additional years were added later, the fit proved to be considerably less satisfactory ('The comparison of the original results with updated results suggests the dangers of projections, even from a good-fitting model, and the possibility that a model may fit well for reasons that are not well understood').

This would appear to be a very interesting field for road safety researchers (COST 239), but also could have important public policy implications, particularly if the success of certain policy interventions can be demonstrated.

2.2. Road safety management

When mass motorisation proved to be accompanied by a growth in road accidents and casualties, many thought that the problems could be solved by apportioning blame for accidents and by punishing the guilty parties. In many countries, this approach is still reflected in police registration forms, which after all, are still designed to determine the question of guilt (as unpaid administrators for insurance companies). Concepts such as speeding, driving too often in the fast lane, crossing without due care and lack of attention are all indications of this kind of thinking. Only later did we realise that this approach bears little relationship to the real reasons for accidents. In fact, the 'guilt-oriented' approach actually prevented the designers of our road traffic systems from feeling any responsibility for

deliberately or inadvertently allowing circumstances with an inherent high risk to continue. After all, it was a question of human error!

Our understanding of the problem of road accidents and the best way to manage it has improved considerably over the last 20 years (see e.g. Wegman, 1995).

A number of important steps can be identified here. The preparation of a matrix by William Haddon (the Haddon Matrix), describing the entire field of road accidents in two dimensions, was of major importance. These dimensions are the parts of road transport system (road users - roads - vehicles) and the three phases of the accident process (pre-crash, crash and post-crash). The subsequent realisation that it is not possible to conceive of a single simple remedy which could lead to control to the overall problem was an important breakthrough. A development of this model can be found in an OECD report on the subject (OECD, 1984).

The next significant step was taken with the publication of a British and an American study into the causes of accidents (Sabey & Taylor, 1980 and Treat, 1980). Both studies showed that accidents often have several different causes ('a combination of factors') and that factors which can be attributed to human error play a role in more than 90% of the accidents. Some have drawn the conclusion that the emphasis in accident prevention should lie on education, in order to avoid human error. This conclusion is wrong (logically speaking) and unnecessarily restricts the scope for effective measures. After all, surely efforts to eliminate human error can be made, for example through good road design?

A final important insight which deserves a mention is that adaptations of the road user's environment (vehicle, road and regulations) do not necessarily lead to the envisaged behavioural changes, but that the behaviour of road users responds to a new situation (OECD, 1990, Evans, 1991). These behavioural adaptations cannot always be predicted accurately in advance on an intuitive basis, and caution is called for especially when substantial safety effects are claimed 'in advance'.

One should realise that driver performance is not the only important factor here. What road users want under particular circumstances also plays a role. Only recently has this issue - quite properly - received more attention in research (see e.g. the SARTRE study, Barjonet et al., 1994). It would also be desirable to obtain a clearer view of the relationship between the quality of public consultation on traffic and road safety problems, the creation of a public support base for certain measures, actual behaviour in traffic and road accidents.

2.3. Conclusions

What does the foregoing mean in terms of the subject of this contribution: the relationship between accidents, human behaviour and road design? First and foremost, that road design is only one of the factors affecting accident risk and the severity of accidents. The design of studies into the above relationship must therefore always be such that the influence of other

factors is known, or is eliminated. We recommend that further research be conducted into the causes of accidents.

A second conclusion is that the possibilities and limitations of road users should play a more central role in road design. Monitoring and evaluation of specific road designs in practice should become a permanent feature of professional practice rather than an exception. This also requires that designers define their assumptions about expected behaviour as explicitly as possible in advance.

Thirdly, efforts should be made to reflect road safety considerations more explicitly in the choice of road design elements than is the case at present. This recommendation also extends to the formulation of design guidelines and manuals.

3. Safety quality of road design

3.1. The inability to learn

A very common approach in the establishment of relationships between road safety and the features of the road network and road design is as follows: a particular part of the road design is made the subject of study and efforts are made to determine a valid and reliable relationship using actual (recorded) accident data. This approach carries inherent problems, in terms of both policy and research.

The research problems will not be discussed in any further detail here. They are of a methodological nature (study design under quasi-experimental conditions involving 'before and after' and 'with-without' comparisons, time series analyses, intervention analyses, how to take account of the fact that there are no constant effects over time and behavioural adaptations, shortcomings in data files, etc.) and of a statistical nature (laws of statistics, small numbers, regression to the mean, etc.).

With regard to the policy problems, the following comments can be made. In many countries there are design guidelines for all types of roads, laid down in large documents (see e.g. Ruyters et al., 1993 and AASHTO, 1994). Such guidelines are based on research findings and also on the views of experts, if the research results provide no conclusive answers. The guidelines often carry substantial status within a country, not least because of the high esteem in which the experts whose names are associated with the guidelines, or the publishers, are held.

Besides more or less binding guidelines, there are also 'best practice' reports. The titles of such publications betray ambition and a desire for authority. What reasons could clients, who are often affiliated to road authorities, have for revising such guidelines? Apart from errors or shortcomings in existing guidelines, one reason for a review could be the desire to include new and improved knowledge and insights in design guidelines.

A second reason could be found in the availability of new design elements (information technology applications, etc.) or in altered conditions (other types of vehicles or vehicle features, growing congestion etc.). Another example of a 'new fact' is the desire to make greater use of low-cost engineering measures rather than total reconstruction of a road.

But there are numerous reasons to decide against innovations in this field. First and foremost, it is very difficult to demonstrate (scientifically) that existing guidelines produce less than optimal safety effects. This lack of knowledge can lead to the view that the existing guidelines are fine as they are. Ignorance leads to non-action.

Secondly, innovative research as a rule focuses on a single aspect of design guidelines and does not, in itself, represent a reason for guideline reform. This, in turn, can lead to lack of interest among researchers. If research is

not asked for and the results are not used, why would anyone still want to be a researcher in this field?

A third reason for not making changes is that research results are often very difficult to translate into guidelines - which is why clients are not too enthusiastic about commissioning research. Another problem is often the cost of research, particularly in a situation where road authorities often face budget cuts.

And a fourth reason lies in the inherent methodological and statistical problems of this type of research.

This leads to the conclusion that the system is inert and conservative: the existence of guidelines for road design and the problems outlined in realising improvements lead to a status quo of non-action. It would be highly advisable to create a 'learning organisation' in this area too. A number of possibilities for this are presented below.

3.2. Road design: guidelines and practice

Roads are designed with several criteria in mind, such as travel time, comfort and convenience, safety, the environment, energy consumption, costs and town and country planning. Some criteria are dealt with in qualitative terms, while quantitative norms are adopted for others. Most of the criteria mentioned interact: some combinations of criteria even produce conflicts. The art of designing a road is predominantly the art of giving the right weight to the various criteria, in order to find the most satisfactory solution.

Safety is usually one of the criteria that are taken into account as a matter of course: at every stage in the design process, the designer is expected to take decisions with safety in mind. But decisions are rarely taken for safety reasons alone. At the end of the process, therefore, it is difficult to judge the extent to which safety has been taken into account.

In general, safety can be considered at four levels (Ruyters et al, 1994):

1. Safety achieved through specific attention paid during the detailed road design process. However, road designers do not always have the right knowledge and awareness needed to give safety enough consideration.
2. Safety achieved through compliance with road design norms and standards. However, although standards, guidelines etc. are written with safety in mind, the authors almost never have quantitative knowledge of the link between engineering decisions and their safety consequences (Hauer, 1988).
3. The level of safety that can be achieved through road classification. However, in practice, correct application of road classification has proved to be a major problem.
4. The (explicit) degree of safety offered by the conceptual transport system satisfying the need for mobility.

Road design standards play a vital role in road design, but major problems exist in this field. This was one of the conclusions of a study commissioned by the European Commission (Ruyters et al, 1994). Not all countries have

road design standards for all types of roads, road authorities do not apply their own standards, some space for interpretation is possible, road safety arguments are treated fairly implicitly in design standards and there is no compatibility between the different countries. The non-availability and non-compatibility of road design standards for the road network in different countries increase risks and therefore contribute to the actual scale of the road safety problem.

3.3. Recent international research

International cooperation in the field of road design and road safety has intensified in recent years. The European Commission has played a particularly stimulating role in this international cooperation, which complements the national efforts. Three activities which make a start on a 'learning organisation' can be mentioned in this respect:

Firstly, the European Road Safety Federation (ERSF) has taken the initiative for the preparation of a number best practice reports. The first will appear very shortly under the title 'Intersafe'. The origins of this report lie in the observation that 'the actual layout of the roads and the way they are being used differ considerably between countries, and even within countries. Without changing any official standard, much can be done in the field of harmonizing the practice of road design, just by making use of the flexibility in the existing standards' (ERSF, still to be published). This report contains a review of readily available knowledge suitable for designing and redesigning roads (major two-lane roads outside urban areas), with a special focus on road safety.

Literature reviews also appear regularly, summarising knowledge in the field of road design (CETUR, 1992, ITE, 1993, Ogden, 1996, Opiela, 1995, TRB, 1987, TØI, 1989). However, it is not the case that all these publications draw the same conclusions regarding identical problems. A very large number of design guidelines recommend central line markings, for example, while an OECD study concludes on the basis of research that there are 'mixed findings with regard to their safety benefits' (OECD, 1990). It would be advisable to compile a list of this kind of unresolved problem as the start for a further research programme.

The European Transport Safety Council (ETSC) is also active in this field, particularly through the Infrastructure Working Party. Publications have recently appeared on the relationship between speed and road safety (ETSC, 1995) and a publication on low-cost measures will appear shortly.

Two projects focusing on road design and road safety recently began as part of the European Union's Fourth Framework Programme. These are the Safety Standards for Road Design and Redesign (SAFESTAR) project and the Advanced Research on Road Workzone Safety Standards in Europe (ARROWS) project.

SAFESTAR tries to fill in some of the gaps in the field of road design. The following subjects will be considered: hard shoulders and emergency lanes along motorways, (long) motorway tunnels, design and use of express roads, design of cross-sections in relation to frontal accidents and skidding off the road, design and, in particular, marking of road bends outside urban

areas, design of large junctions within urban areas and finally, road safety audits.

The ARROWS project is ultimately aimed at producing a practical manual to improve safety for road workers and road users in different types of conditions while roadworks are in progress. Both projects will start just before the summer of 1996 and will lead to results in two years' time.

3.4. Behavioural scientists and road design

Road design should help to ensure that road users can travel efficiently, comfortably and safely. From a road safety point of view, this means that road users should be able to judge the course of a road correctly, should be warned of situations in which they need to adjust their driving behaviour and are given enough time and space for the necessary adjustments. Design guidelines are conventionally based on 'basic assumptions' regarding, for example, reaction times, eye heights, friction coefficients between tires and the road surface, deceleration and acceleration of vehicles, etc. On the basis of assumptions on these factors and the choice of design speed, the stopping distances, sight distances, overtaking distances, lane width, bend curvature etc. can be calculated and incorporated in the design guidelines.

But we have to admit that we still face a major problem in talking about safety on our roads. Traffic engineers and road designers do not know exactly how and why road users behave as they do, and how we could influence behaviour through design. Psychologists and engineers need to work together more closely to improve understanding of road behaviour and to change it in the right ways.

To illustrate this view, an example is given of horizontal curves on two-lane roads (Brenac, 1994). Statistical studies show high accident rates on horizontal curves (1 5 to 4 times higher). Furthermore, sharper curves ten to have higher accident rates than curves with high radii. However, accident rates are only relatively high when the average curvature of the entire alignment is low. High accident rates are observed at bends that follow a long straight line. Moreover, some studies show that internal factors (depending on the design of the curve itself, such as irregularity in the curvature inside the bend) also have significant effects.

Results of behavioural studies provide an indication of the scanning pattern of drivers when they detect a bend, and when they then negotiate a bend. Safe design of curve geometry therefore involves more than deriving the right curvature from a design speed. This conventional concept is not adequate. Introducing the actual speed when redesigning a curve, for example, would be a positive step, but would not be enough in itself.

The introduction of consistency rules for the succession of the different elements of the horizontal alignment (radius of a curve following a straight line, compatibility of radii near two curves) would appear to be necessary from the safety point of view. We could extend this example to other design elements too. Consistency seems to be the key in modern road design and redesign, in order to create predictability and so prevent human error and accidents.

This appears to be an area in which behavioural scientists and road designers must cooperate in order to further improve design guidelines and concrete road design in the future. A great deal is already known about the simplest forms of visual observation (the ability to see stimuli). However, it should be noted here that far less is known about observational differences between different groups of road users (e.g. the elderly). Research into the direction of attention is relatively new, and the identification of (traffic) situations has so far received almost no study. With a view of improved road design, it is recommended that specific research programmes be carried out, which could include a focus on the following subjects: desirable behaviour, particularly at junctions and on bends, in relation to design elements (physical design and appropriate regulations) and the predictability of traffic situations and the behaviour of other road users, leading to self-evident behaviour, by improving recognition of traffic situations (preferably a limited number). The emphasis here should lie on those road categories which currently carry the highest risk (arterial roads inside urban areas and single-lane roads outside urban areas).

4. Proposals for an agenda for the future

4.1. Meta-analyses

The collection of scientifically-based knowledge on the relationship between road design, human behaviour and road accidents proves to create major problems in practice. The research community must make an effort to prevent a situation in which, like Sisyphus, every researcher 'has to roll up his own rock'. Presumably, a number of agreements can be reached on this point.

Firstly, agreements could be made on the continuation of the more or less conventional approaches through literature studies and expert groups (e.g. OECD, ETSC, PIARC). Agreements could also be reached on the performance of meta-analyses. Meta-analyses do not consider each individual research finding as such, but relate research results in accordance with their quality. Interesting examples of such an approach are studies on guardrails and crash cushions (Elvik, 1995) and of the use of daytime running lights (Koornstra, 1993).

Finally, the compilation of research protocols which make research designs more comparable could be considered. This will also make research *results* more comparable and can improve the accumulation of knowledge.

4.2. Best practice guidelines

The production of best practice guidelines, incorporating all available knowledge with a sufficiently sound scientific basis. It is recommended that this type of review is drawn up, periodically updated if necessary on the basis of the latest insights and developments, and brought to the attention of road designers.

4.3. International research and exchange of knowledge

This contribution contains a number of suggestions for further research in the field of road design, human behaviour and road accidents. First and foremost, efforts must be made to increase the 'learning capacity' of this field, not only in substantive terms, but also in organisational terms. This is primarily a task for research institutes (FERSI) and the financiers of this type of research (road authorities). A very obvious step is to increasingly perform such research on an international scale within Europe. Cooperation with fellow researchers in the US (TRB) and other parts of the world could also prove very fruitful, less in terms of the concrete recommendations as in terms of the anticipated harmonization of research methodology.

Another interesting possibility within Europe would be the development of a cooperative research community, for example in a structure similar to that of TRB. A (bi)annual conference could also be linked to such an organisation.

4.4. Encouragement of safety audits as a tool

The use of road safety impact assessments including safety audits (Wegman, et al., 1994) should be encouraged, in order to involve road safety considerations as explicitly as possible in (public) decision-making and so improve the road safety quality of road design. These safety audits could, on occasion, prove to be the key to a 'learning design community'.

4.5. Developing a long term concept ('Vision') to improve road safety

The current strategy in many countries is to realise a safer road system step by step, including in terms of the application of safety principles in road design. A material question here is where we are heading in the long term. Are current risk levels in the highly motorised countries about as low as can feasibly be achieved, or could a road system that is safer by a factor of ten be conceived (the Dutch concept of sustainably safe road traffic system) or even the Swedish ZERO-vision (no severe accident casualties at all)?

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