# Safety effects of road design standards

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# Summary

The paper examines to which degree road safety has been a criterion in drawing up road design standards in EU countries. As safety is among the factors that are mostly dealt with implicitly, the answer to this question is difficult to give. A more explicit treatment of safety is needed to be able to establish and to possibly increase the impact of safety in the standards. Some ways to achieve this are: working in the long term towards a sustainable-safe road network, based on a monofunctional road categorization. In the meantime, a differentiation could be introduced in the status of existing standards, by more clearly distinguishing between regulations, guidelines, recommendations, etc., on the basis of their respective effects on safety. For the sake of international harmonization of standards, a sound system of margins may be needed, allowing designers to depart from certain values, accompanied by a set of well-founded instructions indicating when departures are tolerated.

# Resumé

**Effets sur la sécurité des normes de dimensionnement des routes**

L'auteur examine dans quelle mesure la sécurité routière a été un critère dans l'établissement des normes de dimensionnement des routes dans les pays de l'Union Européenne. La sécurité se rangeant dans les facteurs qui sont plutôt traités implicitement, la réponse à cette question est difficile à apporter. Un traitement plus explicite de la sécurité dans les normes. On présente certains moyens pour y parvenir, en particulier en travaillant sur le long terme vers un réseau routier durable-sûr, fondé sur une catégorisation mono-fonctionelle des routes. En attendant, on pourrait introduire une différenciation dans le statut des normes existantes en distinguant plus clairement entre réglementations, instructons, recommendations, etc. Les intéréts de l'harmonisation internationale peuvent nécessiter un système de marges de tolérance, accompagnées d'instructions rigoureuses sur leurs conditions d'application.

# 1. Introduction

## 1.1. Statement of the problem

Road accidents are the cause of many casualties among road users, in Europe as well as in other countries of the world. About 3% of these casualties are fatal.

All countries have been taking and still take such kind of measures as legislation followed by police enforcement (e.g. drinking and driving; seat belt usage), local improvement of road infrastructure (e.g. expanding the motorway network which is relatively safe; facilities for vulnerable road users), and improvement of vehicle standards.

Although it is hardly possible to assess the effects of individual measures on road accident trends road safety can be influenced in this way. During the last two decades, great progress was made in reducing the accident toll even with a further growth of mobility. However, each year, about 50,000 fatalities and more than 1.5 million injuries still occur in road traffic in the member states of the European Union. This high toll due to road accidents is still considered far more than acceptable.

The cause of a single traffic accident is seldom simple to be established. More often a combination of circumstances is concerned, in which *man*, *road* and *vehicle* play a role. Out of these three, man constitutes the weakest chain, in a sense that the limitations of human capacities are a factor in the major part of the deviations from the ideal traffic processes, leading to accidents.

*In the opinion of the Dutch government, the key to a considerably safer road traffic lies in the concept to create an infrastructure that is adapted to the limitations and possibilities of human capacity through proper road design.*

Besides of this, vehicles should further simplify tasks of drivers and be constructed in such a way as to protect the vulnerable human being as effectively as possible. Also, the road user should be adequately educated, informed and, where necessary, controlled.

*But, proper road design is crucial to prevent human errors in traffic and less human errors will result in less accidents.*

How can we avoid human errors? Three safety principles have to be applied in a systematic and consistent manner to prevent human errors as much as possible:

- preventing unintended use of roads;
- preventing large differences in speed, direction and mass, thus reducing in advance the possibility of encounters with implicit risk;
- preventing uncertainty amongst road users, by enhancing the predictability of the road's course and of the behaviour of fellow road users.

It is to be expected that proper road design, according to these safety principles, could reduce considerably the number of accidents and accident rates. However, it must be admitted that the relationships between safety and road features are not yet well understood quantitatively. As indicated before, the finding of relationships between road design and road safety is obscured by a variety of factors (driver, vehicle, risk increasing circumstances, traffic regulations etc.).

*Road design standards can be of great help in the process of designing roads.*

However, some important problems exist in this field, nowadays. First of all, not all countries have road design standards for all types of roads. And if they have so, they do not always apply these standards. 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 this subject.

Due to the lack of 'hard evidence' about the relationships between road safety and road design, committees responsible for compiling road design standards rely heavily on their own judgements instead of relying on research results. Most of the time they are inclined to use 'the best existing and available information'. And this means, many times, that a limited amount of well-known and cited references are used, lacking better sources. Application in 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 road design standards for the road network in Europe increase risks and therefore contribute to the actual size of the road safety problem on this continent.*

Activities focused on full availability of road design standards and on their mutual accordance are expected to fulfil better the 'three road safety principles' mentioned above and, consequently, are expected to lead to a safer road network. As the cross-bordering traffic increases this argumentation becomes even more valid for harmonizing road design standards on a European level.

## 1.2. Study

The Dutch SWOV Institute for Road Safety Research has studied the question whether proper road design, based on well-established road design standards, could reduce the large number of road accidents on European roads. The project was granted by the European Commission, and was carried out in close co-operation with a number of other research institutes and with the help of experts from most of the member states.

The aim of the project was:
- to analyse the role road safety arguments have played when compiling existing road design standards in the European countries;
- to find ways of increasing the impact of the safety aspect in future design standards.

For this, an inventory was made of the international treaties and the studies and recommendations from international bodies; the competence of these bodies; the legal scope of the treaties and recommendations and its consequences for road safety. Also an inventory was made of road design standards on national levels and the underlying knowledge.

# 2. Road functions

The first safety principle: preventing unintended use of roads, calls for first establishing the intention of every road. In other words:

*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;
- the *access* function: granting direct access to properties (or allowing vehicles to be parked at the end of a trip).

In built-up areas, an other important function of a road (or better: of the public space to which the roads belong) may yet be distinguished: allowing people to stay in the vicinity of their homes, for social contacts or outdoor activities. This kind of 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 the residential function and the (aspects of the) traffic function is even greater. Only the access function of a road could to a certain extent be satisfactorily combined with the residential function.

The occurrence of various combinations of functions on a road is causing problems, not the least with regard to safety.

As an aid to solve the contradictions between all these functions and to nevertheless enable the roads to fulfil their various roles satisfactorily, road *classification* is generally introduced. Road classification means that the shape of a road is related to its functions. 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.

It should be noted that road classification systems in use show several shortcomings. First, road classification is often used by road administrators as an aid to distinguish between roads for *other* reasons than for improving road safety, e.g. for proper managing. Secondly, many roads do not comply with the requirements associated with the various road classes in existing classification systems.

Road classification can be valuable for safety provided that the classification system has been well designed (i.e. targeted on the safety of the road users) and consistently implemented. Possible improvements in this respect are a better targeting of the classification system on road users, and a systematical implementation.

There is a third shortcoming of existing classification systems. Because, in the present situation, more than one aspect of the traffic function may occur on the same road, the differences between subsequent classes often tend to be gradual only, especially if the number of classes is relatively large. Expressing all these differences by introducing distinctions in the shape of the roads is then getting a somewhat artificial character which is no longer understood by the road users.

A fundamentally better situation may be reached by adapting an approach recently developed in The Netherlands. According to this approach every road should have only *one* of the aspects of the traffic function mentioned earlier, i.e. either a through function, a distributor function or an access function. This new conception comes down to the removal of all function combinations by making all roads *monofunctional*. This point is further elaborated in Para. 4.3.

# 3. Design criteria

*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.

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.

*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 are dealt with qualitatively, whereas for others 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. Another 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 result may be unpredictable.

Safety is usually among the criteria that are allowed for *implicitly* and only *qualitatively*: at every step in the design 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.

Safety may only have a more prominent position if the immediate reason for designing a new situation (rather than a complete road) is a hazardous existing situation, like for instance is the case with black spot studies.

In general, safety can be considered at four different levels:

1. *By paying specific attention during the detailed road design process.*
   Road designers do not always have the proper knowledge and consciousness to pay sufficient attention to safety. In any case, as mentioned above, it is not clear to what extent safety has been of influence on the final outcome of the design. Higher levels of safety can be achieved by improvement in this respect.

2. *Through adherence to norms and standards of road design.*
   Each design element implemented in the proposed way has a certain level of safety associated with it. Although this connection is not as robust as previously believed, it is still the cornerstone of geometric design. Some aspects of road design standards will be dealt with later.

3. *Through road classification.*
   It has become clear over the years that certain types of road can be associated with high levels of safety. Better safety records can be achieved through proper application of road classification. This subject was already brought up in Ch. 2.

4. *By considering the (explicit) amount of safety offered by the conceptual transport system satisfying the need for mobility.*
   Safety is seldom considered at this level. In view of the limitations on 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 (in terms of accidents and casualties per vehicle kilometre or per person kilometre travelled) associated with various forms of transport (rail, bus, car, etc.) and on various road types (motorway,

arterial, 30 km/h road, woonerf) should lead us to formulate required safety levels to which the total road network system should be designed.

A first step in this last direction 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.

# 4. Sustainable-safe road categories

## 4.1. History

A new concept for safe road traffic, called a *sustainable-safe* traffic system, was designed as a reaction to the road safety measures of recent decades. Traffic engineers used to improve the safety of the road traffic system primarily by considering the contribution of the separate components of the man-vehicle-road system. Influencing human behaviour, fitting safety constructions to the vehicles and well thought out design and (re)construction of roads and junctions have without doubt exerted a positive influence on the development of road safety. However, there is still no question of a truly fundamental level of road safety.

The number of traffic fatalities in Europe constitutes a sacrifice that would not be tolerated in any other social system. In comparison with rail and aviation traffic, people involved in road traffic run some 100 to 200 times greater risk per passenger kilometre travelled. Road traffic would also find it impossible to meet the standards imposed by society on the working environment, technological-power installations and natural disasters: participation in road traffic per unit of time is no less than 1,000 times more hazardous.

In the road traffic system, non-professional motorists operate, unequipped with automatic pilot, who are still confronted by all types of surprising traffic situations. Not all human error and mistakes can be eliminated through education, training, information, regulations, police enforcement and penalizing measures.

With respect to vehicle safety, a multitude of safety devices are now fitted to motor vehicles, but these will primarily protect the occupants, while not detracting at all from the vulnerability of unprotected road users: quite the opposite!

There are untold traffic situations where, each time, traffic participants are still misled by the road as presented to them or by traffic situations where fellow road users come from unexpected directions.

In an attempt to realize a sustainable-safe road traffic system, a road infrastructure was advocated in which safety is *fundamentally* incorporated, taking into account the interplay with the two other components, man and vehicle.

A road traffic system has traditionally had 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. Not that long ago, the first roads were built in Europe which were specifically intended for rapid movement. Many thousands of traffic fatalities had to occur each year before society became aware of the magnitude of the sacrifice it was prepared to make to satisfy the mobility urge by motorized vehicles.

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.

In those countries where the bicycle has proved a good alternative for the car, promotion activities have commenced to stimulate the use of this means of transport and to design and construct special facilities for slow moving traffic.

On motorways and in residential areas, good results are 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. The manuals published over the last two decades in order to tackle 'black spots' have meantime realized their effect in a number of European countries; the major local 'design faults' which made traffic situations hazardous have been defined.

Despite these curative treatments, two kinds of roads show a high accident risk for all modes of transport, i.e.
- the non-motorways outside built-up areas,
- the non-residential streets inside built-up areas.

It is precisely for these categories that the sustainable-safe system approach should offer a solution.

## 4.2. Philosophy

Traffic situations must offer clear information to road users about transport possibilities and the route and manoeuvre choices. Road characteristics tend to be associated with traffic characteristics; they elicit certain expectations based on experience with combinations of road and traffic characteristics. 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 as he must make unanticipated manoeuvres, thereby endangering road safety.

In many cases, the traffic characteristics can be deduced from the road characteristics, so that continuity in road characteristics can lead to a better anticipation of behaviour in traffic. The way in which road users 'translate' road characteristics into behaviour on the road is subject to assumptions and expectations. This assumed and desirable behaviour in traffic forms the basis for a safe design of the infrastructure. The planners and designers of road networks, roads and junctions will have to take more account of the behaviour and opinions of road users.

The principles recommended here envisage a road traffic system geared towards an efficient - and, most importantly, sustainable-safe - use of the road. The principles are still under discussion and so is their translation into more concrete guidelines for the structure, classification and design of the road network.

## 4.3. Principles

Study has shown that the 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.

For example, many roads which originally had a residential function have meantime acquired a dominant distributor function or even a through function, while still fulfilling the original function as well. It seems quite feasible to adjust the design and regulations associated with a road through a strict allocation of *one* specific function: the *monofunctional* approach.

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 described in Ch. 2, resulting in *through roads, distributor roads* and *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 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 individual road types will be based on the safety principles already mentioned in Para. 1.1:
- prevention of unintended use of a road,
- prevention of encounters with implicit risk, and
- prevention of uncertainty amongst road users.

The conditions, or requirements, to be imposed on a sustainable-safe road network can be characterized as strict in some cases. 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.

# 5. Design standards

*Is there a benefit in using design standards?*

In most countries, geometric road design standards have been set in order to help engineers to design sound roads. Geometric design standards are generally supported on three main grounds (McLean, 1980):
- to ensure *uniformity* among different designs, particularly across administrative boundaries; uniformity makes traffic situations and road user behaviour more predictable, which is believed to be good for safety;
- to enable the *existing expertise* in geometric design, which tends to be centred in the major road authorities, to be more broadly applied; and
- to ensure that road *funds are not mis-spent* through inappropriate design, thus making inadequate provision for future traffic growth and current safe operation.

The first ground mentioned argues for any form of standardization; the others only for a *good* way of standardizing.

To be able to serve these aims standards must have a certain degree of coercion. This may be felt as a support when designing a road. But this status has also its disadvantages. The major disadvantage is the fact that standards diminish the possibilities 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.

In connection with the foregoing, innovative developments are almost impossible if compelling standards have been set.

It appears from this 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 be closely related to the technical soundness of the standard. On this matter, McLean (1980) states:
"The three major bases for the formulation of road geometric design standards were: emperical research, a consensus of good practice, and a rationale, or logical framework."

This gives cause to the following remark. Over the years, it has been assumed that standards and design norms, as they evolved, were derived from a solid base of research. Safety is still supposed to be the major

consideration for most of the design standards and their elements. However, during the past decades, in view of the rapidly changing parameters of the vehicle fleets, and in view of changing public attitudes, the solid foundations of the design norms have been brought into question. "Despite the widely acknowledged importance of safety in highway design, the scientific and engineering research necessary to answer questions about the relationships between roadway geometry and safety is quite limited; sometimes contradictory, and otherwise insufficient to establish firm and scientifically desirable relationships. The standards, guidelines, design procedures and warrants that shape the road system are written with safety in mind, but almost without quantitative knowledge of the link between engineering decisions and their safety consequences." (Hauer, 1988).

Whereas safety ought to have been a major consideration underlying the design standards, its actual impact is doubtful. Possible improvements in this situation might be achieved by:
- assuring a better connection between research results and standards;
- differentiating the status of the standards.

# 6. Status of the standards

There seems to be a large variety in the status of possible starting-points and data used by the traffic engineer. In many cases, he is even unconscious of the exact status of the figures and relations he is applying. Some engineers will tend to accept without criticism every figure or relation they can find, as long as these fit into their approach of the problem. In this context, anything that is written down may be used as a kind of standard.

The less a figure or relation matches with the conditions of the situation or with the aim of a design, the more a designer will tend to inquire into the background of that figure or relation, in order to discover its exact status and to possibly bring this up for discussion.

The background of a standard should be known to be able to determine its firmness. Standards based only upon factual figures and relations would be among the firmest, but it appears that these are rare. Most standards are mainly or entirely founded on more or less realistic assumptions.

An attempt to classify standards with regard to their firmness is made in the Dutch standards for roads inside built-up areas (ASVV, 1988). 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 a specific standard, an analysis should be made of the reasoning behind it and of the nature of the assumptions made. It may then turn out that traffic safety has not been the only criterion in setting the standard. A 'favourable' effect may also refer to the combination of the safety aspect with others. In that case, for example, a facility with only a moderate safety effect may nevertheless be recommended because it does not adversely affect traffic flow and it is also a cheap solution.

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 a differentiation of the status of each standard, will enable the designer to make use of the standards in the most appropriate way.

# 7. International harmonization

In principle, international harmonization of road geometric standards and norms within Europe has the same advantages and disadvantages as apply to the setting of national standards, but now on a larger, international scale. But 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. For some elements there exists a certain amount of agreement between occurring standards, but for others large variations are found. This is an alarming conclusion, especially in view of the expected continuing growth in tourism and trade associated with the European Union and with the opening up of East-West relations.

Several attempts were made in the past to harmonize elements of different standards, with more or less success. Some attempts have led to international agreements reflected in national legislation; others have only resulted in a certain inclination to go along with proposals for an international harmonization on a voluntary basis. Both ways of harmonization can be strongly promoted by producing sound results of research rather than by negotiating.

The fatality rates vary considerably between the countries of the EU. 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 quality of design norms is most likely associated with higher costs.

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

## 8. Margins

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.

As international harmonization is concerned, the question how to treat departures from the standards will repeatedly be raised. 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?

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 when departures are tolerated.

Of course, allowing to depart from a standard is closely connected with the status of the standard (see Ch. 6).

Systems to allow for the use of margins are in force in Portugal and in the United Kingdom.

## 9. Final remark

It is clear that a lot of work has still to be done in this field. It was not the intention of this paper to give final solutions to the problems that were mentioned, but only some impression of the possible ways of finding these solutions.

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