Safety effects of road design standards

A study commissioned by the European Commission DG VII of the situation in the European Union

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Summary

Proper road design is crucial to prevent human errors in traffic and less human errors will result in less accidents. Three safety principles have to be applied in a systematic and consistent manner to prevent human errors: prevent unintended use of roads and streets; prevent large discrepancies in speed, direction and mass at moderate and high speed; prevent uncertainty amongst road users, i.e. enhance the predictability of the road's course and people's behaviour on the road.
It is to be expected that proper road design, according to these safety principles, could reduce considerably the number of accidents and accident rates in Europe.
Road design standards play a vital role in road design. However, the unavailability and the non-accordance of road design standards in Europe increase risks and therefore contribute to the actual size of the road safety problem. Activities focused on the availability of road design standards and their mutual accordance are expected to lead to a better fulfilment of the 'three road safety principles' and consequently to an increase of road safety.

The report deals with the results of a study carried out for the EU by SWOV, in co-operation with a number of other European institutes. The following parts may be distinguished in this study: (1) gathering of information about existing knowledge on the design of road infrastructure elements by: (a) drawing an inventory of international treaties and recommendations, with information about their legal status; (b) drawing an inventory of national road design standards and the underlying knowledge; (2) analysing the role road safety arguments have played when road design standards were compiled; (3) drawing a 'best practice' for road design standards in which considerations, background information and assumptions concerning road safety have been made explicit.
Because of the practical impossibility to deal with all items of road design, detailed studies were only carried out on: cross-sections including medians, shoulders and verges; motorway exits and entries; curves in two-lane roads; bicycle facilities at intersections.
An introductory chapter contains preliminary considerations: status of the standards, assumptions underlying the standards, the question of allowing margins or not, road classification, etc. There is also a chapter which summarizes the research methods to be used when quantifying the relationship between road design standards, accidents and road user behaviour.

The study reveals that existing national standards in Europe only rarely contain information on the safety effects of the road designs that are recommended or even prescribed by now. To enable the design of safer roads, more clarity is needed about the relationship between layout and safety aspects of the infrastructure elements. Then, also, a harmonization of design standards towards a common high European level of road safety could be better aimed for.
Some concrete findings from this study are recommended to be included in the set of warrants for the Trans European Road Network.

Contents

Notice to the reader

This volume is the main report on safety effects of road design standards which was compiled by SWOV in collaboration with other European partners, in 1993-1994. The annexes that go with this report are listed below.

The project was carried out with financial support of the Commission of the European Union. However, no authority of the European Union has responsability for the contents of this publication.

The main report is a composition of contributions from various authors, edited by SWOV and published in both English and French. The annexes were not re-edited but were published in the form in which they were furnished by the authors. SWOV is not responsible for the contents of annexes that were produced by authors from outside the institute.

The full publication consists of the following volumes.

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Annex I: Road classification and categorization
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Annex II: Assumptions used in road design
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Annex III: Methods for investigating the relationship between accidents, road user behaviour and road design standards
G. Maycock & I. Summersgill; Transport Research Laboratory, Crowthorne, England

Annex IV: International organizations and road design standards
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Annex V: National road design standards
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Annex VII: Road design standards of medians, shoulders and verges
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Foreword

Transport safety, and especially road safety, is of major concern to all responsible for transport policy in the European Union and its Member States. Based on different expert reports the Commission of the European Union has proposed an Action Programme on Road Safety to the Council of Ministers, which was accepted in 1993. Based on one of the priorities set in this Action Programme the Commission (DG VII) and the SWOV Institute for Road Safety Research from the Netherlands joined forces and launched a study on road design standards and road safety.

The SWOV, in close co-operation with a number of other research institutes and representatives of road authorities throughout Europe, has studied the question whether proper road design, based on well-established road design standards or guidelines, could reduce the enormous toll due to road accidents on European roads. To carry out this study SWOV looked for co-operation with experts from different countries. In order to improve the possibilities to collect relevant information from the twelve member states and to gain as much commitment as possible amongst experts in this field, it was decided to contract different research institutes and to organize workshops.

SWOV wants to thank all researchers who have contributed to this study by preparing parts of the report: Thierry Brenac (INRETS, France), Shalom Hakkert (Technion, Israel), Lene Herrstedt (Vejdirektoratet, Denmark), Geoff Maycock (TRL, United Kingdom), Lech Michalski (Technical University Gdansk, Poland), Jürgen Steinbrecher (Germany), and our SWOV-colleagues Marjan Hagenzieker, Theo Janssen, Herald Ruyters, Chris Schoon, Pim Slop and Fred Wegman.

Experts from seven countries have attended workshop meetings in which SWOV and different authors were advised and where drafts of the different chapters were discussed. SWOV is most grateful for the contributions made by all participants attending these workshops: João Cardoso (LNEC, Portugal), Don O'Cinnéide (University College York, Ireland), Kenneth Kjemtrup (Vejdirektoratet, Denmark), Wilhelm Kockelke (Universität Siegen, Germany), Sandro Rocci (Euroconsult, Spain), Roland Weber (BASt, Germany). Also Mr. Luc Werring and Mr. Eduardo Morere Molinero from the European Commission, Directorate General of Transport, have made valuable contributions.

Besides their contribution to the content and the editing Herald Ruyters, Pim Slop and Fred Wegman have managed the project adequately, which resulted in completing it as agreed.

We do hope that the results will have impact on the European Commission and all relevant international bodies and institutions.

Matthijs Koornstra
director SWOV

1. Introduction

1.1. Statement of the problem

Each year, accidents are the cause of about 50.000 deaths and more than a million and a half injuries on the roads of the European Union. This high toll due to road accidents is considered as unacceptable, by all Member States of the European Union and by the European Union itself.

In many EU Member States the number of road accident fatalities and casualties reached a peak level around the beginning of the seventies. During subsequent years great progress was made in reducing the road accident toll even with a further growth of mobility. The change in the amount of road fatalities and casualties in a jurisdiction turns out to be the result of two autonomous processes: the change in the amount of traffic, which is a result of population growth and economical growth and which can be reflected by the annual traffic mileage, and the change in accident rate, expressed as the number of fatalities per unit of mileage. The annual change in mileage is for most countries in the world without exception positive and the fatality rate is decreasing steadily. However, the reduction percentage is differing from country to country. This reduction of fatality rates throughout the years can be understood as the more or less constant effect of subsequently improving the quality of our road transport system: better roads, better vehicles and more qualified and more experienced road users.

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), improvement of road infrastructure (expanding the motorway network, which is relatively safe, facilities for vulnerable road users), improving vehicle standards. Although it is hardly possible to assess the effects of individual measures on road accident trends, it can be stated road safety can be influenced.

Seldom the cause of a traffic accident is very simple. More often a combination of circumstances plays a role, in which man, road and vehicle are of importance. The key to a considerable 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 simplify tasks of drivers and be constructed to protect the vulnerable human being as effective as possible. Last but not least, the road user should be adequately educated, informed and, where necessary, controlled.

Proper road design is crucial to prevent human errors in traffic and less human errors will result in less accidents. Three safety principles have to be applied in a systematic and consistent manner to prevent human errors:
- prevent unintended use of roads and streets, after having defined the function of a street: flow function (rapid processing of through traffic), distributor function (rapid accessibility of residential and other areas) and access function (accessibility of destinations along a street while making the street safe as a meeting place);

- prevent large discrepancies in speed, direction and mass at moderate and high speed, i.e. reduce the possibility of serious conflicts in advance;
- prevent uncertainty amongst road users, i.e. enhance the predictability of the road's course and people's behaviour on the road.

It is to be expected that proper road design, according to these safety principles, could reduce considerably the number of accidents and accident rates compared with the existing situation in Europe. However, it has to be admitted that the relationships between safety and road features are not 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).

Road design standards play a vital role in road design in all EU member states. But 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 leads to different road design even in the same jurisdiction. Further on, 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 literature 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 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 the availability of road design standards and their mutual accordance are expected to lead to a better fulfilment of the 'three road safety principles' and, consequently, to an increase of road safety. As the cross-bordering traffic increases, this argumentation becomes even more valid for harmonizing road design standards on a community level.

1.2. Purpose of the study

The scope of the project can be described as:
- to gather information about existing knowledge on the design of road infrastructure elements, by:
(a) drawing an inventory of the international treaties and the studies or the recommendations made by international bodies; the competence of these bodies; the legal scope of these treaties and recommendations and the consequences thereof for road safety;
(b) drawing an inventory of road design standards on a national level and the underlying knowledge;

- to analyse the role road safety arguments have played when road design standards were compiled;
- to draw a 'best practice' for road design standards in which considerations, background information and assumptions concerning road safety have been made explicit.

The results of this project in draft are offered for consideration to the organization dealing with the Trans-European Road Network (TERN), more in specific to the Action Group #2, operating under the Motorway Working Group, that is in charge of the Standardisation of Road Typology (START). The task of the Action Group START is to define an European level of services in terms of geometric and maintenance harmonization, a harmonized system of road signs and general road information, leisure and service facilities and motorist information. The two first mentioned subjects are of importance of this study.

Attention is paid to motorways and to other types of roads as well. A majority of all accidents happen on secondary roads outside built-up areas and on roads inside built-up areas. It is to be expected that major improvements can be achieved on these types of roads.

1.3. Organization of the study

To carry out this study a subvention was received from the European Commission (DG VII). SWOV developed a project plan in the first months of 1993. In order to improve the possibilities to collect relevant information from the twelve member states and to gain as much commitment as possible amongst experts in this field, it was decided to organize two workshops. Experts from seven countries have attended these meetings. Moreover, SWOV decided to invite institutes to carry out parts of this study: Transport Research Laboratory from the U.K., INRETS from France, Technical University of Gdansk from Poland, Steinbrecher from Germany and the Danish Road Directorate.

During the first workshop a tentative structure and content of the report was discussed. During the second workshop drafts were discussed of all chapters. We consider this consultation from experts from different Member States as an ideal working method for this type of study.

1.4. Structure of the report

This report is based on eleven contributions as described in Annexes I-XI. The main findings, conclusions and recommendations are summarized in this report.
In Chapter 2 preliminary considerations are presented dealing with design standards and the way road safety arguments are incorporated in standards. This chapter illustrates which are the important features in this respect, to mention only a few: status of standards or guidelines, assumptions used in road design, allowing margins in standards etc.
Chapter 3 summarizes the research methods to be used when quantifying the relationship between road design standards, accidents and road user behaviour.

International organizations have some competence over road design standards. The national standards and the international agreements dealing with this topic are described and analysed in Chapter 4.
Because of the practical impossibility to deal with all items of road design, only a limited amount of detailed studies were carried out on specific problems. Results of these studies are presented in Chapter 5: design of cross-sections (para. 5.1) and medians, shoulders and verges (para. 5.2). Features and safety aspects of exit and entry facilities on motorways are presented in para. 5.3. Para. 5.4 deals with curves in two-lane roads and para. 5.5 with bicycle facilities at intersections.
Conclusions and recommendations are presented in Chapter 6: 'Best practice'.

2. Preliminary considerations

2.1. Road functions

Roads are built with one major function in mind: to enable people and goods to travel from one place to another. Differentiating within this *traffic function* as a whole, individual roads may serve parts of the total travel process in particular: some roads cope with long distance traffic only, others play a role as distributors in areas with scattered destinations, and some roads just grant direct access to properties alongside or allow vehicles to be parked on them at the end of a trip. In the following sections, a distinction will be made between three aspects of the traffic function:

- flow function: rapid processing of through traffic;
- distributor function: making districts and regions accessible;
- access function: allowing properties to be reached.

The distinction between the functioning of roads as described here is often not so clear. In the present situation, most roads are *multifunctional*, i.e. they perform a mixture of the elements of the traffic function in varying combinations. This is when problems arise because the three elements 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.

In built-up areas, another important function of a road (or: 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. The contradiction between the requirements for satisfying this *residential function* and the (elements of the) traffic function is even greater. Only the access function of a road could, to a certain extent, be combined with the residential function. A more extensive description of the functions that roads may have is given in Annex I to this report, Chapter 4 (see Janssen, 1994).

2.2. Design criteria

Roads are designed with several criteria in mind, such as: travel time, comfort and convenience, safety, environment, energy consumption, costs, town and country planning. Some criteria are dealt with qualitatively, whereas we adopt quantitative norms for others.

Most of the criteria mentioned are of mutual influence; some combinations of criteria are even conflicting. 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 satisfying solution.

Not all criteria are dealt with in the same way. Whereas 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: 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 has also usually no particular position and must compete with the other criteria. 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. Black spot studies are a good example of this.

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

1. *Safety achieved through specific attention being paid 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 which extent safety has been of influence on the final outcome in the design. Higher levels of safety can be achieved by improvements in this respect. We will not go any further into this aspect here.

2. *Safety achieved 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, as described below, this connection is not as robust as previously believed, it is still the cornerstone of geometric design. Several aspects of road design standards are discussed in para. 2.4.

3. *The level of safety that can be achieved through road classification.*
It has become clear over the years that certain types of road can be associated with high levels of safety, especially the types of road with distinct roles as discussed before: motorways serving long distance travel only, and properly adjusted streets in residential areas. Better safety records can be achieved through proper application of road classification. This subject is brought up in para. 2.3.

4. *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 diverse road types (motorway, arterial, 30 km/h

road, woonerf) should lead us to formulate required levels for which the total road network system should be designed.

Only recently, an attempt in this last respect has started in the Netherlands, in developing the concept of *sustainable safety*, i.e. the creation of a transport infrastructure that can provide an acceptable level of safety in the long run (SWOV, 1993).

Also recently, a number of countries (especially the United Kingdom) have initiated a procedure called a *safety audit* associated with the design of large road work projects. The audit ensures an independent review of the design process as to guarantee that the highest possible level of safety has been achieved, and that no design details are included which could be detrimental to safety.

Finally, whereas safety is implicitly built in into the design process through its relationships with the various design elements, it can also be considered in its wider relationship with the road environment. A large proportion of accidents (up to 40% of motorway accidents in some countries) are single vehicle accidents in which a vehicle runs off the road or overturns. Proper attention to *roadside design* and treatment of roadside obstacles can reduce the number and severity of such accidents considerably.

Whatever action may be taken, a more explicit treatment of safety is needed.

2.3. Road classification or categorization

As an aid to solving the contradictions between functions mentioned in Section 2.1, and to nevertheless enable the roads to fulfill 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 function combination of a road is made clearer to the road users by means of distinct features.

It should be noted that road classification systems in use have several drawbacks. First, road classification is often used by road administrators as an aid to distinguish between roads for reasons other than for improving road safety. In addition, 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 (concentrated on safety) and consistently implemented.

Possible improvements in this respect are a better targeting of the classification system on road users, and a systematic implementation of this classification system.

There is another shortcoming of most road classification systems. Because more than one aspect of the traffic function may occur on the same road, the differences between the 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 becoming somewhat artificial.

A fundamentally better situation may be reached by adopting an approach recently developed in the Netherlands. According to this approach every road should have only *one* of the elements of the traffic function mentioned earlier, i.e. either a flow function, a distributor function or an access function.

This new concept comes down to the removal of all function combinations by making all roads ***monofunctional****; it is elaborately described in section 2.8 as an element of the so-called 'sustainable-safe' road system.*

2.4. Design standards

In most countries, geometric road design standards have been set in order to help engineers design sound roads. Freely rendered from McLean (1980), geometric design standards are generally supported on three main grounds:
- 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 misspent* through inappropriate design, making inadequate provision for future traffic growth and current safe operation.

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

To be able to serve these aims, standards must have a certain degree of 'compellingness'. The major disadvantage connected with this 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. In the most favourable situation, he can only choose one 'pre-fried' solution out of a range of two or three that come possibly into consideration.

But even then, 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, closely related to that of its technical soundness. The status that a standard may have is dealt with in para. 2.6.3.

On the matter of the technical soundness of standards, another statement of McLean might be of interest:
"The three major bases for the formulation of road geometric design

standards were: empirical 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 stated or assumed that standards and design norms, as they evolved, were derived from a solid base of research. 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. Referring to current U.S. road design standards, Anderson (1980) states categorically that they ignore large percentages of existing vehicles, drivers and road surfaces.

Safety is supposed to be the major consideration for most of the design standards and their elements. However, Hauer quotes from a 1987 TRB Committee report:
"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."
Hauer (1988) then goes on to summarize that:
"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."

Whereas safety should have been a major consideration underlying most design standards and their elements, it is becoming clear that its assumed implicit value have come under substantial criticism.

A possible improvement in this situation might only be achieved by a better connection between research and standards.

This asks for sound evaluation methods; see Chapter 3.

2.5. 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. 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 large variations are found for others. Referring to the last paragraph of Section 1.1 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.

The fatality rates vary considerably between the countries of the EU. Harmonization of design standards tends to incline towards the higher norms accepted in some countries, thereby augmenting levels of safety. In this lies also one of the possible drawbacks of harmonization, because a higher quality of design norms is likely (though not always) associated with higher costs. Another drawback might be the radical change in standards that could be necessary in some countries.

Harmonization may also be hindered in the case of different driving behaviour and cultures to be currently noticed in the countries involved. However, at least on motorways, these differences should be banned as soon as possible.

2.6. Assumptions used in road design

2.6.1. *General*

Most road design standards give definite instructions for the layout of the various elements of a road: dimensions or even complete drawings are provided. Information on the background of these instructions is only rarely added. There is no indication of the relative importance that was given to road safety, in comparison to traffic flow, easy reach of destinations, environment, costs, etc. Often, it is not even clear to what extent a certain standard was based upon factual figures and relations and to what extent upon assumptions. One cannot get around factual figures, but assumptions can be altered or at least deviated from occasionally. With regard to this, it should be known how firm a certain assumption is; and whether it is to be considered as an underlying basic assumption or as an occasional assumption.

As underlying assumptions could be regarded assumptions of a universal nature; they are not likely to vary between countries because they refer to figures and relations with a predominantly objective character.

At least, they should not vary. But assumptions of this kind are not at all identical in the national standards. This partly explains the differences in certain values for concrete design elements in the various standards, like the minimal radius for a convex vertical curve.

This conclusion requires to first harmonize the underlying assumptions. It is expected to be a relatively easy job because the objective character of the assumptions is not likely to cause much trouble in harmonizing.

A search has been carried out to find records of such underlying assumptions in the various national standards. It appeared that information on such assumptions is difficult to find. In the Dutch standards for motorways and for non-motorways outside built-up areas, separate volumes have been dedicated to what is called 'basic criteria'. Likewise, in the Danish guidelines for urban traffic areas, a separate volume deals with 'premises for the geometrical design'. In other standards, this kind of information is either lacking or, at most, hidden in the text.

It looks as if information on the underlying assumptions in the field of traffic engineering is to be found in textbooks rather than in the national standards. However, textbooks were not the subject of this study. A first tentative list of elements that could be regarded as underlying assumptions is given in Annex II to this report (Slop, 1994).

Due to the fact that separate presentations of underlying assumptions could hardly be found there is no clear notion of what are to be exactly considered the underlying assumptions. For this reason, it was first investigated what 'underlying assumptions' may imply (see para. 2.6.2). During this activity, the idea to develop a systematical approach to the problem was born; this will be dealt with in para. 2.6.4.

2.6.2. *Figures and relations*

More generally speaking, when designing a road - whether using standards or not - frequent use is being made of figures and relations, but not all figures and relations used are equally firm. A primary distinction should be made between:
- factual figures and relations; and
- assumed figures and relations.

Factual figures can be gathered by observing reality. If invariable physical data is concerned one observation is sufficient and only one figure will, of course, be correct (type **F1**).
Examples: the dimensions of one particular vehicle; measurements of the existing situation.

If a quantity may have various values more observations are needed to get an idea of the range of possible values occurring. In this case, the information can be given in the form of a distribution, or as an average with an indication of the variation (type **F2**).
Examples: distribution of car lengths; average running speed of vehicles on a road, with standard variation.

Some data can hardly or not be directly observed. They have to be gathered in a different way. The figures needed in a particular case can, for instance, be drawn from statistics. Here they are also considered factual figures, as long as a discussion on them is not likely (type **F3**).
Examples: percentage of disabled persons; hazard figures for existing road types.

Factual figures are normally more or less constant over a long period of time. Possible changes in them set in only slowly. But factual figures may differ substantially between countries. Most information of this kind needed to design a project is known in one way or another; sometimes only very specific information still has to be gathered.

As *factual relations* are here considered logical relations, mathematical relations and physical relations that are not subject to controversy (type **FR**).
Example: stopping distance in a particular situation, given initial speed and decelaration.

Factual figures and relations make up the basic data for designing roads, but they are not sufficient. They may even constitute a minority of the data the designer relies on. In addition, assumptions must repeatedly be made to obtain workable starting-points for the traffic engineer.

In all cases in which one certain value for a quantity is needed, but not known and not to be obtained, a *figure* should be *assumed*. This is often done by choosing one value out of a range of factual values, p.e. the average or in other cases the 85 percentile value of a distribution. If this choice is based upon a common opinion among experts on the subject the assumption can be classified as generally accepted. In other cases, the assumption is made on the basis of one or more investigations the result of which is assumed universally applicable. Then, the 'users' of this assumption rely on the authority of the draftsman of the assumption. Here, all these cases are called type **A1**.
Examples: human reaction time; dimensions of design vehicles.

In some cases, such a figure chosen is not meant to be an approximation of existing reality, but a target value, meant to create a desired situation. These figures sometimes give the impression of being more or less arbitrarily chosen (type **A2**).
Examples: design speed; friction coefficients; acceptable gradients.

Figures are sometimes calculated as the result of factual relations. But if the parameters used in the calculation are assumed figures, the result can also bear the status of 'assumed figure' only. Above, for instance, the stopping distance was presented as a factual relation of the initial speed and the deceleration. But to be able to indicate a necessary stopping sight distance in a particular situation a maximum initial speed and a minimum deceleration must be assumed.

As *assumed relations* could be considered relations leaning on theories which describe a process in such a way that calculations may be made on it (type **AR**).
Examples: human information processing; theory of the influence of various kinds of road unevenness on skid resistance.

The assumption of the figures and relations may be made by the designer himself, but, in many cases, this was done for him before. It may have been the legislator who did it: legally made assumptions; or other engineers may have done it for him before: 'common practice'. Generally speaking, road design standards try to minimize the variety of actual designs by prescribing or recommending the use of certain assumed figures and relations.

2.6.3. *Status of the standards*

There seem to be large differences 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. It may then turn out that assigning the figures and relations according to the classification proposed in para. 2.6.2 is not always that easy.

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 the standards with regard to their firmness is made in the Dutch standards for roads inside built-up areas. The facilities described are distinguished as follows:
- *regulations* to be complied with (*****);
- *guidelines* which can be deviated from 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 (*).

Technical arguments have not been the only criteria for the classification. A five star classification may have been given to a layout that is by no means the safest solution to a problem, but just because it is prescribed, often on the basis of other considerations as well.

To get more insight into the 'technical' firmness of 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. A 'favourable' effect may e.g. also refer to the combination of the safety aspect with others. In that case, 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.

By way of example, a brief analysis of this kind is given below. The subject is the shape of a vertical curve on a crest.

The problem with vertical curves on a crest is that approaching road users cannot look over the top. An obstacle on the road behind the top may thus not be seen in time to stop before it. Design standards for the shape of such curves are generally based on the following line of thought.

The curvature must be flat enough to enable an approaching car driver with an assumed minimum eye height to perceive an obstacle with an assumed minimum height at a distance far enough to be able to stop before the obstacle. This distance is among others determined by the approach speed of the car, the conspicuity of the obstacle, the perception/reaction time of the driver, the braking capacity of the car and the friction coefficient of the road surface. Figures must be assumed for all these factors.

2.6.4. *Systematic approach*

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 it in the most appropriate way.

The approach that will allow this is shortly outlined in the step-wise procedure described below.

1. Draw up a classification system for (facts and) assumptions, e.g. in the way as is tentatively done in para. 2.6.2.
2. Classify each (fact or) assumption according to this system.
3. Assign a degree of technical firmness to each assumption, depending on how solidly the assumption is based on research, e.g. in the way as is described in para. 2.6.3. (As facts are facts, their degree of firmness is 100%; unfortunately, facts seem to be rare as starting-points.)
4. Analyse on which (facts and) assumptions a particular standard has been based.
5. On the basis of no. 4, draw up a conclusion about the technical firmness of the standard.
6. Ascertain that the degree of technical firmness of a standard is reflected in its status.
7. Make a connection between the status of a standard and the possibilities for slackening.

2.7. **Margins**

National standards sometimes contain specified margins around certain values, which may be used by the designer 'in emergency'. Unfortunately, it is rarely indicated what situations can be described as emergencies.

As international harmonization is concerned, the question of how to treat departures from the standards will repeatedly be raised. Must these be tolerated, and under what conditions? Ought margins 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.

Allowing to depart from a standard is closely connected with the status of the standard (see para. 2.6.3).

2.8. **Sustainable-safe road categories**

2.8.1. *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 safety. Each year, many thousands of traffic fatalities are registered in Europe, a sacrifice that would not be tolerated in any other social system.

In comparison with rail and aviation traffic, people run some 100 to 200 times greater risk in road traffic per passenger kilometre travelled. Road traffic would find it impossible to meet the standards imposed by society on the working environment, technological-power installations and natural disasters: participation in traffic per unit of time is no less than 1,000 times more hazardous.

In the road traffic system, non-professional motorists operate, who are not equipped with automatic pilot, but 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 penalising 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 the unprotected road user: quite the opposite!

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. Even on the well-designed motorways, situations arise which lead to serious accidents.

In an attempt to realise 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 motorised 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 into Europe on a broad scale. In those countries where the bicycle has proved a good alternative to the car, promotion activities have commenced to stimulate the use of this means of transport and to design and construct facilities for slow traffic. This represents an acknowledgement of the differentiation in road function. A road is not only intended to allow rapid transport by car, it also serves other modes of transport, and even other needs than simply mobility. It has also become clear that many of these road functions cannot be combined on one and the same road.

At both extremes of the scale for road function - the motorway on the one hand and the 30 km/h roads in the residential areas on the other - good results are gained in reducing the risk to road users. However, there are clearly many roads remaining in the intermediate, 'grey' zone 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 realised 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 categories of roads show a high accident risk for all modes of transport, i.e. the non-motorways outside built-up areas and the non-residential streets inside built-up areas. It is precisely for these categories that the sustainable-safe system approach should offer a solution. This approach is intended to make the road traffic system fundamentally safe through preventive measures.

2.8.2. *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 a certain expectation from driving behaviour, based on experience with combinations of road and traffic characteristics. For example, motorists driving on roads with divided carriageways, wide lanes and a straight course will generally anticipate high speeds and not take into account slow traffic and intersecting traffic at junctions, exits, crossings and the like. However, if on such a road unexpected traffic characteristics occur (for example, the presence of an agricultural vehicle) or a sudden change in road characteristics (for example, 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 under discussion and hence, their translation into more concrete guidelines for the structure, classification and design of the road network.

2.8.3. *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 function they are expected to fulfil.

For example, many roads which originally had a residential function have meantime acquired a dominant district distributor function or even a flow function, while still fulfilling the original function as well. It seems quite feasible to adjust the design and regulations associated with a road via a strict allocation of one specific function on the basis of the safety principles formulated here:
- prevent unintended use of a road,
- prevent encounters with implicit risk, and
- prevent erratic behaviour.

By using three functionally related road categories with largely unequivocal characteristics and codes of behaviour, these principles can be met to a significant degree. These functions are once again described:
- flow function: the rapid processing of through traffic;
- distributor function: the collection and dispersion of traffic to and from districts and residential areas on the one hand and flow roads on the other;
- access function: making private property accessible.

These three functional road categories are not hierarchical and do not differ in importance. Therefore, instead of classification, the term categorization is more appropriate. It is applicable to roads both inside and outside built-up areas. The frequency of properties alongside and in the immediate vicinity of the road does determine its design. So do traffic volumes of course, specifically with regard to the cross-section of the road. Depending on the frequency of properties and on vehicle volumes, several road types may be distinguished within one road category. The point is to keep the function of the road clear to road users, despite differences in design.

Based on the three principles named above, the functional conditions for a sustainable-safe road network can be formulated. These will then be examined in brief and made available for discussion. The traditional principles, such as uniformity of the infrastructure, continuity of traffic flows and consistency of the road design are also considered.

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.

2.8.4. *Proposals for a road categorization*

The system is based on three categories, equivalent to the three elements of the traffic function. This leads to a classification into flow roads, distributor roads and access roads. Depending on the required capacity and on the immediate environment (rural or urban, inside or outside a built-up area) we can distinguish several models within each category, to be denoted as road types. A description is given in Annex I, para. 5.2.

2.9. References

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3. Methods for investigating the relationship between accidents, road user behaviour and road design standards

3.1. Introduction

The safety effects of design standards can only be measured by observing the change in accident numbers which results 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. There are therefore 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. In the final section of this chapter a brief account will be given of the techniques which might be used to assess the behavioural aspects of design standards. A fuller treatment of these topics is given in Annex III to this report (see Maycock & Summersgill, 1994).

3.2. The before and after approach to safety assessment

The basic principle of before and after assessment is to estimate the accident effectiveness of a design change by comparing the number of accidents that have occurred during a period of say 3 or 5 years before the design changes have been made with the number of accidents ocurring after the change. 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 usually denoted by α); 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 unlikely to be adequate. Three will be considered: they are (i) the basic randomness of the accident data, (ii) the need to correct for systematic changes over time, and (iii) bias by selection.

Randomness in the accident data means that the number of accidents in the before period (b) and the number in the after period (a) are both unreliable measures of the true long-term accident rate. Because of this it is necessary to use statistical techniques to judge whether α is really different from 1 (the no-change value) or whether the value obtained would have occurred purely by chance. The methods available for making this assessment are described in the Annex III to this report.

The main disadvantage of the before and after approach to the assessment of accident changes is that inevitably, 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 however, in most situations there will be a whole range of factors which are likely to change with time. The most common method of allowing for such changes is the use of 'control' sites. The principle involved 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 which may affect the before and after accident numbers at the trial sites is assumed to affect the control sites to the same extent. 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.

There are two important aspects to the use of controls in before and after studies. The first is that for controls not to introduce excessive variability into the estimates of effectiveness, they must contain relatively large numbers of accidents. The second is that to be effective as a control, 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 - and it is equally difficult to devise objective ways of choosing the best.

Finally, bias by selection. When choosing sites for treatment, safety engineers often use some form of selection criteria. If sites which have a high accident rate in one particular year are chosen for treatment, then purely by chance, accidents will have fallen the year following treatment, even if the treatment has had no effect whatsoever. This phenomenon is known either as 'selection bias' or 'regression to the mean'.

In carrying out before and after studies the researcher needs to be aware of the problems outlined above and the range of techniques - discussed in the Annex III to this report - available to minimise their effects.

3.3. The cross-sectional approach to safety assessment

Measures of the safety effectiveness of design standards can 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. 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.

The approach adopted is to identify a suitable sample of sites on public roads which includes a range of examples of the design feature of interest for which accident data is available; the traffic flows and the key geometric variables at these sites are then measured, and the resulting data is analysed to obtain accident/flow/geometry relations.

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 features of the design 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 geometric features, from sites in which the feature of interest has a range of values. A single period of time is involved, so that the problems associated with the time difference between before and after observations of accident data are avoided.

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. In order to determine the effect of design parameters on accidents reliably in a multi-variate context, it is essential to have the full range of values of the important variables represented within as large a sample of sites as possible. Sites should also be selected to give a broad geographical spread. Traffic flow data should be collected on a weekday, and the counts factored to provide an estimate of the flows relevant to the accident period for each type of vehicle and manoeuvre. Sites should not be selected on the basis of their accident record, since this would lead to 'bias by selection' in the accident models. After the sample of sites for the study has been selected, the geometric variables to be examined in the analysis must be selected, defined and measured on site.

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. 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 Annex III gives an example of the kind of models which can be constructed and illustrates how they might be applied to design.

3.4. Methods for use in behavioural studies

Although as far as road safety is concerned accidents are the fundamental measure of the effectiveness of the design, they are an *output* of the driver-vehicle-road system. Accident analysis does not necessarily provide insights into the complex behavioural mechanisms involved in the operation of a highway. For this it is necessary to undertake studies which examine various aspects of driver behaviour. For convenience, the techniques reviewed will be considered under three main headings - field studies, laboratory studies and questionnaire survey methods.

The most straightforward way of measuring behaviour is to observe what drivers actually do on the roads - usually without their knowing that they are being observed. Most studies undertaken for traffic engineering purposes are of this type. So, measurements of speed/flow/geometry relations enables the average journey speeds on a route to be related to the characteristics of the route. Studies of the capacity and delay at junctions make use of observed behaviour at a range of junction types for the prediction of the traffic performance of these junctions. This kind of observational study is not primarily concerned with safety, and treats traffic in the aggregate.

A more direct way of obtaining information about individual drivers is to undertake in-vehicle or laboratory studies. In-vehicle observation methods come in two forms, one in which drivers are observed whilst driving their own cars, and the other in which drivers drive specially instrumented cars. In both cases, the drivers drive on public roads. These methods allow extensive data to be collected about low level handing performance - steering, accelerations, braking, etc. Psychological response data - risk assessment, arousal levels, stress, fatigue, task demand, visual awareness and so on - can also be collected simultaneously by means of verbal assessments at cued points during the test drive. Basic personal data such as age, sex driving experience, accident histories and so on are of course, readily available.

The disadvantage of the technique is that the driver's know that they are being observed, and that apart for choice of route, the experimenter has relatively little control over the actual traffic situations likely to be encountered during the test drive. Laboratory studies allow the experimenter more control over the experimental conditions.

A laboratory study involves measuring some aspect of a driver's performance or ability in some sort of experimental facility. Studies of this kind may involve a variety of measurement techniques ranging from non-driving related tests of some aspect of the driver's performance, through to the execution of realistic driving tasks in a driving simulator. At the simplest level, the abilities measured in laboratory studies might include among others, performance characteristics such as static and dynamic visual acuity, reaction times of various kinds, tracking ability, the ability to carry out divided attention tasks, or to recognize embedded figures, or the detection of movement in depth. This type of study does not measure qualities which specifically relate to road design standards, but aims to discover those abilities which relate to the accident liability of individual drivers.

The measurement of 'higher order' skills need a more sophisticated visual input than that required for the simpler visual and reaction time tests. One way of providing such complex input is to use a driving simulator. Simulators are already in operation in Sweden (at VTI), Germany (at Daimler Benz) and the Netherlands. France, Japan, and the UK are in the process of constructing simulators of different degrees of complexity. However, providing a realistic portrayal of a complex traffic situation in a simulator is not an easy task, nor are simulators cheap to use in experimental studies. However, sophisticated driving simulators undoubtedly have their place for studies of driving which demand a high degree of control on the part of the experimenter over the parameters of the experiment.

Finally, in the context of the methodology for studying the impact of road design standards, questionnaire and interview surveys are important. Postal questionnaires are a powerful way of eliciting information from large samples of drivers; they enable self-reported accident data to be collected relatively cheaply from which the accident liability of individual drivers as a function of age, driving experience and sex can be obtained. Some aspects of the drivers' psychological characteristics can also be collected using self completion questionnaires. Such measures might for example, include: scales of social and driving deviance and self assessed speeding behaviour, thoroughness in decision making and driving style, attitudes to risk perception and risk acceptance in the driving task and illusory biases.

The purpose of obtaining this kind of information in the context of design standards, would be in order to attempt to link the features of the design - design speed, sight distances, overtaking provision, visibility, signing, lighting, and so on - to the individual characteristics of the drivers who are using the roads. There is relatively little of this kind of work reported in the literature. However, in the present review of methodology, it seems important to include these methods of behavioural and psychological investigation, since designers of the future may well need to have a greater understanding than they have of present, not simply of the 'average' driver, but also of the distribution of characteristics of the driving population for whom they are making provision.

3.5. Reference

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4. International and national road design standards, an overview of the existing geometric road design standards

4.1. International organizations and road design standards

4.1.1. *Introduction*

Road design standards and traffic regulations are most of the time a matter of national interest. As geographical, historical, psychological and still other conditions differ from country to country, it is rather evident that those questions, that rule road design and traffic, are treated at a national level.

As traffic tends to cross borders and international traffic is increasing, international regulations and standards are nowadays indispensable. A certain degree of harmonization is necessary to present the user of road infrastructure a more or less continuous image of a set of road types and traffic.

At the same time, it is of importance that the level of safety is about the same in all European countries. This would benefit the road user, especially those who travel abroad.

In this study, the international organizations are presented in a linear order, with decreasing competence. The international agreements that emanated from these bodies, are analysed. A more extensive treatment of this paragraph is given in Annex IV to this report (see Ruyters, 1994a).

4.1.2. *European Union*

The most important organization in this perspective is the European Union. This does not refer due to the work done in the past, but more to the potential this organization has. Actually, it is the only international organization that can enforce by legal means the decisions taken. It therefore is a very effective organization for harmonization, also to confirm the work already done by other international bodies.

As the Maastricht treaty on the European Union entered into force on 1 November 1993, new fields of competence were attributed to the Union. A new provision on road safety was inserted in article 75 and a whole new chapter on trans-european networks (article 129) was added.

Article 75, sub 1 says: "For the purpose of implementing Article 74 (general article on transport delegating competence to the European Union), and taking into account the distinctive features of transport, the Council shall, acting in accordance with the procedure referred to in Article 189c and after consulting the Economic and Social Committee, lay down:
(a) common rules applicable to international transport to or from the territory of a Member State or passing across the territory of one or more Member States;
(b) the conditions under which non-resident carriers may operate transport services within a Member State;

(c) *measures to improve road safety*;
(d) any other appropriate provisions."

The articles 129b, 129c and 129d form the new Title XII of the Treaty of Rome, inserted by the Maastricht' treaty on the European Union, on 'Trans-european Networks'. Article 129b defines the objectives of the Trans-european Networks, article 129c the actions and article 129d the procedures. One of the actions article 129c distinguishes, is: "(In order to achieve the objectives referred to in Article 129b, the Community) shall implement any measures that may prove necessary to ensure the inter-operability of the networks, in particular in the field of technical standard-ization".

Competences in the field of road safety and infrastructure have been clearly attributed to the EU. Further action will be undertaken, but for a first period, given the principle of subsidiarity, the exchange of information and the study of main points of interest will be carried into execution. For the long term, the European Union will be the principal actor in this field, because of the delegation of power in the field of transport from the Member States to the Union and because of the legally binding juridical acts the Union can draw up and which can be enforced by legal means.

The principle of subsidiarity is a code of conduct. This principle says that only those actions that can be undertaken more efficiently by the Member States all together, will be executed by the European Union (Art.3,b, Treaty of Rome, as amended by the Maastricht' treaty). For all other actions the more appropriate level for execution will be the national or regional one.

In the field of road safety and infrastructure a more complex situation seems to occur. As the European Union will be a prime investor in infra-structure, it is rational that decisions are coordinated with the Member states at that level. The execution of the projects occurs, however, at a national and even a regional level. The planning of infrastructural invest-ments is a matter of both European and national interest. The outcome could be that the European Union fixes a set of criteria which new infra-structure has to fulfill.

At this moment, the Commission of the European Union is studying the policy concerning road safety and infrastructure. A ongoing study in the field of road safety like this one is closely related to infrastructure.

In the field of infrastructure, the EU is establishing a network, called the Trans European Road Network (TERN). This network is formally ap-proved by the Council of the EU, but the TERN will have to be approved once more due to the the newly introduced co-operation procedure. This new procedure, introduced by the Maastricht' treaty, gives more rights to the European Parliament.

Meanwhile, working groups have to provide the necessary background thoughts for this network. One called START (Standardization of Road Typology) elaborates road design standards for this network. The infor-mation this study will produce, will through the Commission hands come to the use of this working group.

4.1.3. *United Nations - Economic Commission for Europe*

The United Nations' Economic Commission for Europe is the international organization which is of great importance to the field of infrastructure, and, to a lesser extent, to road safety. They have build up a long experience in this field of interest. The treaties of the E.C.E. are the only existing international treaties. They can not be enforced, but they remain of value as a starting point for international discussion, and form the basis for further treaties

The most important agreement on this subject is the European Agreement on Main International Traffic Arteries, usually called AGR, which is the French acronym (Accord Européen sur les Grandes Routes de Traffic International). It established of the E-road network. The AGR has annexes that among others provide road design standards.

Recently, very similar standards, but much more detailed ones, have been fixed for the TEM network, which is the Trans-European North-South Motorway, a network in central and eastern European countries. These standards have guidance from the ECE, but do not form part of a UN-agreement, so they have another status than the AGR.

Other international agreements exist for standards on specific subjects. There are several international agreements on road signing and marking from the UN-ECE and from the European Council of Ministers of Transport (ECMT). Most important are the UN Conventions on Road Signs and Signals of 1949 and of 1968. The UN also elaborated a European Agreement in 1971 and a Protocol on Road Markings in 1973, supplementing the '68 agreement.

These Conventions on Road Signs and Signals of 1949 and 1968, should not be confounded with other important UN agreements of 1949 and 1968, i.e. the Conventions on Road Traffic, which are also supplemented by an European Agreement of 1971.

The conventions and agreements incorporated in the Draft European Road Traffic Rules have been subject to regular updating and amendments. It therefore is a very actual and useful document. The Annex II of the AGR-treaty, dealing with the conditions international traffic arteries have to fulfil and which is of concern to this study, has been updated in 1988. The updated version seems however a less precise document that therefore is not a very elaborated starting point for further harmonization. It is an example that harmonization in the field of infrastructure is very difficult.

The main conclusion that can be drawn, is that AGR, which is the only international agreement in this field, is not strict enough. It gives very few 'standards' and recommendations are formulated unprecisely. Moreover, AGR utilizes a road classification that confuse the users of the E-road network because this network varies from bendy, narrow two-way single carriageway roads up to large motorways, all having the same E-number signposting.

4.1.4. *European Councl of Ministers of Transport*

The European Council of Ministers of Transport is another forum for international co-operation in this field. It has a similar position as the UN-ECE and is working on the same files in close collaboration with the UN-ECE, the European Union and the OECD. The Council of Ministers can adopt Resolutions, which are of a similar value as the treaties of the UN-ECE because they are almost always adopted in national legislation.

In 1975, the ECMT consolidated the treaties of the E.C.E. into what is called a 'European Highway Code'.

4.1.5. *European Committee for Standardization*

Reference should be made to work done in an other body: CEN, the European Committee for Standardization. CEN is working in technical committees that each have a specific object for which they discuss technical harmonizations. A committee that is of interest to this study, is TC226, which deals with European standards on road equipment. This TC is composed of several Working Groups (WG), which deal with specific topics, like there are road restraint systems, road markings, vertical signs, noise barriers, etc. Though CEN standardises, it does not fix road design standards. CEN is not making policy, but it is setting functional requirements.

4.1.6. *Other organizations*

Other international organizations like OECD, FERSI, IRF, IRU, PIARC, AIT and PRI are important and known for all the work they fulfill as organizers of congresses, contractors of studies, by which a lively exchange of information is created. OECD and PIARC are the main actors in the field of research. Their working area is clearly defined (OECD: transport, PIARC: road transport) and their research is organized in a very effective way. FERSI is the principal actor for road safety research. PRI is the independent body for organizing campaigns and the transfer of information. IRF and IRU are the organizations that defend the interest of the road constructors and the professional road users. AIT is acting in the interest of road users. As such, they can provide valuable information on the state-of-the-art of the roads and their usage.

4.1.7. *Conclusion*

A schematic representation of all these international agreements and other co-operation forms, could be the following (in chronological order):

Title	Year	Body	Members
Convention on Road Traffic	1949 and 1968	UN-ECE	UN-ECE members
European Agreement	1971	UN-ECE	UN-ECE members
Convention on Road Signs and Signals	1949 and 1968	UN-ECE	UN-ECE members
European Agreement	1971	UN-ECE	UN-ECE members
Protocol on Road Markings	1973	UN-ECE	UN-ECE members
'European Highway Code'	1975	ECMT	ECMT members
'European Road Traffic Rules'	1990	UN-ECE	UN-ECE members
European Agreement on Main International Traffic Arteries (AGR)	1975 (amended annexes 1988)	UN-ECE	UN-ECE members
TEM - Standards and Recommended Practice	1992	UN-ECE	UN-ECE members
TERN	1993 (and 1995?)	EU	EU members

4.2. National road design standards

In this document, a summary of the geometric road design standards of the Member States of the European Union is given. Standards on signing and marking and operational regulations are sometimes mentioned, sometimes not. National road design standards are existing in all twelve countries of the European Union. The form in which they do exist, their date of publication, their use, their legal status and their updating are different in all countries.

The purpose of this chapter is to give the correct names of the road design standards in force today in the Member States of the EU. A short description of the status of the standards is given, as well as comments on ongoing work on the standards. A more extensive treatment of this paragraph is given in Annex V to this report (see Ruyters, 1994b).

In a table, without mentioning the names of the standards themselves, the road design standards of the Member States of the European Union are regrouped in two categories: rural and urban. For each category, a distinction is made between mandatory and non-mandatory standards.

This table is concerning geometrical road design standards only. It is, given the amount of standards existing, likely to be incomplete, but the table has to be read in connection with the comments below.

	Rural		Urban	
	mandatory	non-mand.	mandatory	non-mand.
Belgium	X			
Denmark	X	X		X
France	X			
Germany	X			X
Greece				
Ireland		X		
Italy	X		X	
Luxemburg				
Netherlands	X	X		X
Spain	X	X		
Portugal	X	X		
United Kingdom	X	X		X

In Greece and Luxemburg no specific standards are existing; both countries use standards of other countries. Greece is developing its own standards.

The other ten countries all have standards for rural roads. Only five countries have standards for urban roads, which are non-mandatory in four cases (Denmark, Germany, the Netherlands and the United Kingdom), but which are mandatory for Italy. This seems a matter of competence: the national state is in general responsible for the national network which is of reduced length and of 'high' quality. It is relatively easy to establish mandatory standards, for such a network, often consisting of motorways and express roads. The rest of the network is under the responsability of regional or local administrations. As there are many different administrations in one country, road design differs a lot from one to the other situation. The surrounding conditions play an important role here. The road design standards for urban roads are therefore in most of the cases guidelines or recommendations. The status of the urban road design standards in Italy is not quite clear.

In all ten countries, road design standards of the rural network apply to urban areas as far as urban roads form part of the national, state-owned, network.

The situation concerning road design standards for rural areas is even more complex. A common practice in all countries, also in Greece and Luxemburg, is the appliance of standards through project approval. If there are deviations of departures from standards, the project approval assures there is some control.

Standards in Ireland are non-mandatory. This is also the case concerning non-motorways in the Netherlands, for which a separate set of standards exists, and concernig the rural roads of the local network in Portugal. There, the difference is that the same standards as for the national network are being used, but then not on a mandatory base, but more as guidelines. For all four mentioned countries, deviations have to be well reasoned. In Denmark most standards are non-mandatory; but some specific ones, p.e. on sight, are mandatory for all roads.

Belgium has mandatory standards for both the national road network and for the regional (Flemish and Walloon) networks. In France and Spain mandatory standards do exist for the national network. These standards are mostly used by the regional authorities (départements in France, the federal countries in Spain) as well. In Spain, standards have to be approved by the Ministry in a long legal procedure. Some standards remain guidelines only.

Two special situations are existing in Portugal and the United Kingdom. In Portugal, the standards for the national road network have a special system for deviations. If 'normal' maximum or minimum values can not be met, or only by annexing high amounts for construction costs, 'absolute' maximum or minimum values are applied, the use of which is subject to project approval. A similar system is used in the United Kingdom. There, it is a three tier system: desirable minimum standards, relaxations and departures. For relaxations of the desirable minimum standards no ministerial approval is necessary, but conditions for relaxations are formulated in the standards. Departures have to be approved by the Ministry.

The discussion on the status of the standard is an essential one. A designer of a road relies upon an approved, mandatory standard. If the information contained in the standard is insufficient to judge the consequences of deviations, it will be difficult to make a design in which the road safety component is well balanced.

In Europe, different approaches to this problem are existing:
- project approval, but uniform application can not be garantueed in this way;
- status of the standard: mandatory standards, guidelines, recommendations, but generally the designer is confronted with a lack of material to make a well balanced design;
- the two (Portugal) or three (United Kingdom) tier technique, which can give the designer more insight in the standard.

It can be recommended to look for a best practice concerning the existing approaches. The safety component would certainly be enhanced.

4.3. References

Ruyters, H.G.J.C.M. (SWOV) (1994a). *International organizations and road design standards.* A-94-6. Annex IV to SWOV-report Safety effects of road design standards).

Ruyters, H.G.J.C.M. (SWOV) (1994b). *National road design standards. An overview og geometric road design standards of the Member States of the European Union.* A-94-7. Annex V to SWOV-report Safety effects of road design standards)

5. Detailed studies

5.1. Cross-section design

5.1.1. *Introduction*

For the identification of the main reasons and criteria for road cross-section dimensions, three sources were taken into consideration:
- the knowledge relating to relationships between road geometry and operational, economical and safety aspects;
- conclusions from the comparison of dimensions provided in different standards;
- facts and assumptions presented in national guidelines.

In the evaluation of cross-section dimensions, national and international standards were compared:
- standards used in the Netherlands (NL), France (F), Belgium (B), Great Britain (GB), Germany (G), Italy (I), Ireland (IR), Danemark (DK), Portugal (P), Spain (SP);
- Trans-European North-South Motorway (TEM), Standards and Recommended Practice;
- revised text of Annexes II and III of The European Agreement on Main International Traffic Arteries (AGR);
- road typology in the Trans-European Road Network, Non-Motorway Link, START.

Standards used in Greece and Luxembourg were not available. Comparisons carried out by the Technische Hochschule Darmstadt and by the University College Cork were the starting point for evaluation of road design standards.

Cross-section dimensions, basic criteria and safety effects of lane widths and shoulder widths were compared for the following road types:
- rural motorways
- rural non-motorway divided roads (including dual carriageway expressways).
- undivided roads (including single carriageway expressways and ordinary roads with a design speed higher than 60 km/h).

A more extensive treatment of this paragraph is given in Annex VI to this SWOV-report (see Michalski, 1994).

5.1.2. *Elements affecting width standards*

Factors affecting cross-section width

The factors that determine the cross-section are:
- road network factors: road function, design speed, average trip length of vehicles;
- traffic factors: traffic volume, type of vehicles using the road, width of passenger cars and heavy vehicles, number of pedestrians, volume of cyclists;
- road factors: alignment, drainage, number and function of traffic lanes and shoulders, construction practice, maintenance procedures;
- human factors: drivers' behaviour in speed and lateral position, behavioural adaptations, fealing of security;
- environmental factors: landscaping, access requirements, aesthetics;

- safety considerations: accidents rates, severity of accidents, accident costs;
- operational requirements: required level of service, capacity, delays;
- benefit/cost analysis: construction, maintenance, accident and operational costs.

Operational effects

Operational effects of lane and shoulder width can be analysed through the use of lanes by different type of vehicles, the use of shoulder by moving and stationary vehicles, lateral position, running speed of vehicles, freedom of manoeuvre and operating costs. American studies suggest that paved shoulders of rural undivided roads improve the lateral separation between oncoming vehicles. This separation depends on width and type of shoulders. German analysis of the lateral distance shows that drivers let their driving behaviour depend primarily upon the presence of an emergency lane, the width of traffic lanes, the speeds and the volume of traffic on the lanes.

A review of research results indicates that narrow pavement widths have some effect on vehicle speeds on low volume rural roads. As traffic volume increases, the operational benefits derived from a full-width paved shoulder increase. They are significant at volumes greater than about 200 veh/h, when paved shoulders appear to let increase the average speed on the carriageway by at least 10 percent and limit the number of the vehicles that are in platoons to less than 20 percent.

In a German study it was found that up to a traffic volume of 1200 veh/h in one direction the average speed of trucks on sections without emergency stopping lane showed a reduction in speed of 7 km/h when the width of lane was less than 3.5 m. Citing the HCM-85, a reduction of lane width from 3.6 m to 2.7 m causes capacity reduction of 19 percent, but reduction from 3.5 to 3.25 m causes very little reduction of capacity.

Safety

The conclusions of studies looking to the relationships between lane width, shoulder width and shoulder type and accidents, especially on two-lane rural roads, were often not only inconsistent, but in many cases contradictory. Nevertheless, findings show that rates were the highest for run-off-road and opposite-direction accidents for narrow lanes and decreased as lane width increased. Rates for other accidents generally increased as lane widths increased. It means the only accidents that would be expected to decrease with lane widening were run-off-road and opposite-direction accidents. As with lane width, the run-off-road and opposite-direction accident rates decreased as shoulder width increased to 2.7 m. There was a slight increase in accident rates for shoulders 3.0-3.7 m wide. Analysis of the combination of lane and shoulder widths indicates that a greater reduction in accidents can be realized by lane widening rather than by shoulder widening. However, the unadjusted accident rates were approximately the same (or slightly higher) for 3.6 m lanes as for 3.3 m lanes, possibly indicating the limit beyond which further increases in lane width are ineffectual.

Evaluation of the accident studies from the stretches in Germany led to the result that the frequency of accidents due to 'errors in overtaking, being overtaken, and changing lanes' was higher than average on roads with narrow traffic lanes (3.25 m).

Comparison of accident rates and accident cost rates for German rural roads shows that paved shoulder on non-motorway divided roads does not cause significant improvement in accident rates, but the lack of central reservation causes double increase of accident cost rates.
Results of safety research carried out in Switzerland show that increasing the single carriageway width to 8.5-10.0 m decreased accident rate as well as the casualty rate, but for the widths between 12.0 m and 14.0 m both rates increased again. These and some other findings question the validity of the until now, undoubted hypothesis "the wider the road, the safer it is".

Costs relationships
The analysis of the total economic consequences of the choice of road cross-section type and its optimal dimensions requires the inputs of some costs components into the calculation. From a practical point of view, parameters can be divided into three groups:
- parameters independent of the road: length of time period in question, opening year, traffic development, percentage of heavy vehicles;
- parameters dependent of the road: capacity, volume/speed relationships, accident rates, construction costs, maintenance costs;
- economical parameters: costs per accident by severity, hourly price for cars and heavy vehicles, driving costs, discount rate.

The results of cost-effectiveness calculations for two-lane roads in USA show that:
- the relatively high costs for providing full pavement width and wide shoulders against the expected safety benefits for very low volume is evident;
- there are optimum widths for given traffic volumes.

5.1.3. *Basic criteria for cross-section dimensions in national standards*

A few considered standards give explanations on established width of cross-section elements. Sometimes standards present different approaches to the chosen road alignment and cross-section dimensions, definitions and importance of design speed, possibilities of departures from standards as well as the role of guidelines for users in the designing process. Therefore standards contain:
- cross-section dimensions for some types of road; usually the modification of standards must be avoided, or
- cross-section dimensions and the basis for justifying those dimensions is also given, or
- cross-section dimensions and procedures for the choice of optimal cross-section or for the consequent determination of the departure from the standards.

Design vehicle and dynamic space
Minimal width of traffic lanes and paved shoulders depends first of all on design width of vehicles and side margins determined by lateral position and dynamic space of moving vehicles. For rural roads the width of the 'design heavy vehicle' is established. Usually, in Europe it is 2.5 m, in the Netherlands 2.6 m is allowed.
In German standards, minimal lane width results from the sum of 2.5 m heavy vehicle width, 0-1.25 m side margin and 0.25 m additional space strip, if there is opposite traffic lane. It creates a traffic lane width from

2.75 to 3.75 m. Side margins depend on speed limits. In Dutch standards, as a result, traffic lane width ranges from 3.35 m to 3.50 m for motorways and from 2.75 m to 3.25 m for single carriageway roads.

Lane width
With regard to motorways, eight EU countries (F, IR, G, I, B, UK, SP, P) use one value of traffic lane width, independently of design speed. Traffic lane width range from 3.25 m to 3.75 m. Only Dutch standards provide 3.25 m lane width, 0.25 m less than the minimal width admitted by AGR. However the Dutch width of 3.25 m is rarely being used and only for a design speed of 90 km/h.
Generally, the effect of design speed on lane width is not noticed.
In Dutch and TEM standards, the lane width depends mainly on design speed, in Danish standards the lane width depends also on economic reasons (wide and narrow cross-section).
Danish guidelines present the procedure for economic calculations; British guidelines propose the COBA program for optimalization. All standards provide one cross-section width except Irish and German standards, which serve two widths depending on design speed and the network function of the road.
On non-motorway divided roads, lane widths range from 3.25 to 3.75 m. The width of 3.75 applies to a design speed of 100-120 km/h.
Traffic lane width of undivided roads ranges from 2.5 m (DK) to 3.75 m. In five standards (IR, I, G, DK, NL) reduction of lane width is connected with a decrease in design speed. The width of a lane in the British standards relates to traffic flow.

Paved outer shoulder width
Outer paved shoulder width (emergency stopping lane for motorways) varies considerably, from 2.0 to 3.75 m. AGR stipulates at least 2.5 m. Only two standards (F, DK) provide a width below this value. On average, lanes for a speed of 100-120 km/h are a little wider than for 80 km/h. Paved shoulder width for motorways in French standards depends on design volume or special economic conditions, in Irish standards this width depends on design speeds; in Dutch standards it depends on the number of lanes, in Danish standards it depends on economic requirements.
There is a total disagreement on the outer paved shoulder width of non-motorways. These types of roads are in use with or without wide paved shoulder, so the width of the total pavement ranges from 7.5 m to 11.5 m. Paved shoulder widths for non-motorways in Irish standards are connected with the road class.
Only some standards explain the function of paved shoulders. There are no explications on shoulder dimensions for non-motorways divided roads. For undivided roads there are considerable differences in dimensions of paved shoulder width in combination with the verge width. In Irish standards wide paved shoulders are combined with wide verge, in Dutch and Danish standards narrow paved shoulders with a wide verge, in Spanish wide paved shoulders and narrow verge are described. The effect of shoulder functions is notable. In Irish, Danish and Dutch standards, shoulder width is connected with design speed. Wide shoulders provided in Dutch standards have the substantiation in American accident research which confirms that 80 to 90% of off-road accidents occur less than 10 m from a carriageway.

Pavement width
Pavement width results from all above-mentioned factors, first of all design vehicle width, margins between moving or standing vehicles, design speed, type and function of paved shoulders. The choice of typical pavement width in design standards depends on economical, operational and safety reasons. Because of the maintenance requirements, the pavement width of 12.0 m is recommended in Dutch motorway standards and of 11.5 m in German standards. This width may be used temporarily as a four-lane carriageway, for example during road works on the parallel carriageway.
Undivided road pavement widths of 6.0-12.0 m are used in design standards.
It is stressed in some standards that the designer will have to choose the road types according to the criteria dictated by economical analyses. Sometimes conditions like the inadequacy of the area, the size of earthworks provoke the reduction of cross-section width. French guidelines propose a certain succession of reductions. Danish standards propose the narrow type of cross-section for dual carriageway roads. Also British standards use special cross-sections with restricted width.

5.1.4. *Conclusions and recommendations*

1. The comparison of motorway cross-section width shows relatively great agreement of standards. The majority of EU countries uses a *lane width* of 3.75 m. The width of 3.25 m is rarely used and only for a design speed of 90 km/h. For *paved shoulders*, only two countries use a width below 2.5 m, as recommended by START. *Pavement width* ranges from 8.0 m to 12.0 m for one direction.

From a safety point of view one can state that:
- widening a traffic lane over 3.5 m causes no significant improvement of the accident rates, so a lane width of 3.5 m can be recommended;
- safety effects of 3.25 m lane width for *urban* motorway should be investigated in different countries in order to determine safety consequences and using conditions;
- widening a paved shoulder (emergency stopping lane) over 2.5 m causes no significant improvement of the accident rates;
- the safety effects should be investigated of a total pavement width (11.5-12.0 m) of one carriageway for 2x2 lane motorways, which are required for maintenance reasons (to make temporary use of one carriageway as a four lane two way road).

2. Non-motorway divided roads showing one or more motorway characteristics have high accident rates. The use of wide paved shoulders on these roads in different countries depends on some additional factors like road network structure, landscaping and multifunction of the road link. Even though wide paved shoulders can have some advantages for safety, the possibility of emergency stopping is probably only a minor benefit. Therefore, a paved shoulder with a width comparable to the full width of an emergency stopping lane seems not to be necessary.

3. Undivided rural roads have considerable different dimensions of traffic lanes and shoulders. In many cases two-lane roads with wide paved shoul-

ders are used like four-lane roads. Based on safety research one can conclude:
- cross-section dimensions with environmental features should make the impression of 'narrow cross-section' being simultaneously a wide 'soft' road space;
- four-lane undivided roads should be avoided in rural areas;
- on higher speed roads of this kind, a paved shoulder can have a width of 1.8-2.0 m; a different colour of the shoulders could stress the special functions of these lanes, different from the functions of the main lanes;
- using of emergency lay-bys every kilometre and wide verges can be recommended to design practice.

4. The standards and guidelines which are used in EU Member States present different approaches to the design process offering different range of facts, assumptions, explanations, rules and recommendations. This creates problems when compiling a 'best practise'. Therefore it can be recommended:
- to create national methodological documents for the use of designers and planners with guidelines references for road safety;
- to agree on fundamental facts, assumptions and definitions (e.g. design and running speed, cross-section elements, design vehicles dimensions).

5. The safety aspect is only one of the factors affecting cross-section dimensions and is particularly important in the design practice. A conscious safety design requires that designers know the safety implications of their decisions.
It is necessary:
- to indicate in guidelines both the optimal range of cross-section dimensions and the indispensable values from a safety point of view;
- to create clear procedures for economic calculations and estimation safety benefits;
- to evaluate the safety consequence, when departing from safety standards;
- to determine savings due to accident reductions depending on lane and shoulder widths before and after widenings.

6. The type of cross-section and its dimensions together with other geometrical features, determines the character of a road. Critical review of the available literature dealing with the safety effects of cross-section standards indicates inconsistency or, in many cases, contradictory conclusions. However, research has established that lane and shoulder conditions directly affect run-off-road and opposite-direction accidents, but also overtaking-related accidents.
It is necessary:
- to undertake further national and international studies to create the most likely relationships between accident frequencies and severities and lane width, shoulder type and shoulder width for different types of cross-section, traffic conditions and accessibility, environmental features;
- to undertake research directed towards a better understanding behavioural adaptation of the road users of cross-section design dimensions.

5.1.5. *Reference*

Michalski, L. (Technical University of Gdansk) (1994). *Cross-section.* A-94-8. Annex VI to SWOV-report Safety effects of road design standards.

5.2. Medians, shoulders and verges

5.2.1. *Introduction*

In most of the European countries approximately one quarter of all casualties are killed in accidents with obstacles. From a road safety point of view a safe design of the roadside is of great relevance.
A safe design of the verges is intended to *prevent* occupants of vehicles that leave the road from *(serious) injury*. This means that a zone with rigid obstacles (but also steep banks and canals) should be situated at a sufficient distance from the road, or that the zone should be protected by means of a crash barrier.

For a strategy with respect to the design of verges, three general design principles can be distinguished which are applicable to both divided and undivided roads. These are listed below, in order of preference:
- In the first design, an *obstacle free zone* regarded as the safest of all, there are no hazard areas or obstacles. Vehicles leaving the road can go on running freely or perhaps can be brought under control.
- In the second type, a *zone with single obstacles*, there are located roadside furniture and single rigid obstacles. Roadside equipment like lighting poles and traffic signs have to be designed in a way that, if hit by a motor vehicle, they do not endanger the occupants. The rigid objects, if there is no way to remove them, will have to be protected separately (i.e. with a crash barrier of short length or with an impact attenuator).
- The relatively least safe area, a *full protected zone*, has a hazard area too close to the carriageway. This should be protected full lengthwise with a crash barrier.

O'Cinnéide and others (1993) have conducted a data collection of dimensions of cross-sections in fifteen European countries. From this survey and from this study the following conclusions could be drawn: Both in the German and the Dutch standards is described which obstacles has to be protected with a crash barrier (i.e. trees, poles, steep slopes). Also the obstacles which can be placed in a not protected verge (i.e. aluminium poles, traffic signs, alarmposts), are indicated.

The national road design standards are not very clear low a roadside could be designed safely; agreement exists between the European countries in case the median and shoulder are protected with crash barriers; however, less agreement between the countries regarding a safe design of the unprotected medians and shoulders. Especially the question remains to establish the widths of the obstacle free zones, so that no crash barriers are required.

5.2.2. *Rural motorways*

Medians, protected with crash barriers

The most extensive well-reasoned safety aspects in the guidelines have been drawn up by the German and Dutch road traffic authorities (FGSV, 1989; RWS 1989).
The crash barriers will be positioned at a sufficient distance away from the carriageway. With the presence of a barrier a certain distance from the barrier to the carriageway should be included in order to take into account the so-called safe driving distance. This distance depends on the design speed of the motorway. The same regards the dimension of the redressing zone. In the table the dimensions are given.

A. Safe driving distance:
design speed: ≥120 km/h: 1.50 m
design speed: <120 km/h: 1.00 m
B. Redressing zone:
design speed: ≥120 km/h: 1.00 m
design speed: <120 km/h: 0.50 m

Based on this relationship the cross-sections of medians with crash barriers can be determined.

Medians, unprotected

If a vehicle can be brought under control in a obstacle free zone, there is no need for a crash barrier.
Criteria obstacle free zone:
- median may not be crossed at an accident
- prevention of turning manoeuvres.

Shoulders, protected with crash barriers

Based on the dimensions of the width of lorries of 2.5 m, the width of the emergency lane is put on 3 to 3.5 m. The agreement on this width is found in 12 countries.
The clearance between the edge of the emergency lane and the guard rail is put on 0.5 m or more. An agreement is found in 9 of the 15 countries.
The distance between the painted marking of the right traffic lane and the guard rail is the sum of the dimensions of the emergency lane and the clearance. As a consequence of the widths just mentioned this total distance amounts to at least 3.5 m.

Shoulders, unprotected

The German and Dutch guidelines express a preference for obstacle free zones. With respect to width, these were partly determined on the basis of American studies from the 1970s.
Only a few studies concerning obstacle free zones were carried out in Europe. At most of these studies the verge width was below 2 to 3 m. As far as known a Dutch accident study dating from 1983 (SWOV, 1983) was the only one with large zones. In this study the relation is determined between the number of accidents with trees and the distance of the trees to

the edge of the pavement. The tree accidents are related to the total number of accidents. As variable the motor vehicle intensity (ADT) was involved.
Based on these studies, Dutch guidelines stipulate widths varying from 10 m for motorways to 4.5 m for single carriageway roads with a design speed of 80 km/h (both calculated from the border line of the traffic lane). At this moment there is less support for these dimensions from the European countries. Further research is recommended.

5.2.3. *Consensus and differences between EU-countries*

Based on the background to the guidelines, a table has been drawn up (see Table 1 in Annex VII to this report). This table shows all parts of the cross-section including the width of obstacle free zones.
The table indicates per road category under the heading *'best practice'* the dimensions of the sections of the cross-section. These dimensions are based on a professional judging of the optimal level of safety and the feasibility.
Following this, it is indicated under *'agreement'* how many countries have included corresponding widths in their guidelines and under *'disagreement'* for which number of countries this is not the case.
The final two items in this table give the dimensions as cited in the two reports about the guidelines concerning European roads. The first report is prepared by the Motorway Working Group, Action START (1994) in the framework of the Trans-European Road Network. This report describes the conditions which this road network must comply. The second report concerns a German survey of the Darmstadt Institute of Technology concerning a comparison of the guidelines for road design in countries of the European Community (Durth, 1987).
Where the question marks have been placed in the table, further research is needed.

5.2.4. *Further research*

This chapter deals with the points on which there is less agreement between the countries concerned. It concerns the widths of the obstacle free zones so that no crash barrier is required.

The expressed preference for obstacle free zones in the German and Dutch guidelines is useful for study. However, it is unknown whether these guidelines are being followed with the construction of new roads. To date, no evaluation has taken place. It would seem highly advisable to carry out such an evaluation and to asses safety effects of the recommendations about obstacle free zones.
Further it is equally desirable that those countries which apply reduced verge widths should join this study and determine the proportion of obstacle accidents. It goes without saying that a distinction should be made to the road type. Such a study would help to chart the problems associated with obstacle-related accidents, so that basic knowledge is gathered which can be of assistance in determining the desired widths for obstacle free zones.

If the median is sufficiently wide, there is no need for a crash barrier. The question is what width is considered sufficient. The Dutch guidelines suggest 20 m. This distance is so large, however, that only few countries can concur with this. To attain at a reduced width, the foremost criterium to be adopted should be that the median may not be crossed, neither in an accident situation nor with turning manoeuvres. It is therefore essential to realize a physical separation which does not lead to excessive impact deceleration for those vehicles that leave the road. This separation also has to be to prevent the crossing of heavy vehicles (lorries and buses). The dimensions such a physical separation should have and the distance at which it should be placed from the road is subject for research.

5.2.5. *References*

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5.3. **Exit and entry facilities on motorways**

5.3.1. *Introduction*

It is to be expected that Inter-European road traffic will increase. Most of the traffic crossing the borders will flow on motorways. Road design of motorways usually follows national guidelines and regulations, so one can find a lot of differences in the appearance of motorways. Yet, it will have to be investigated yet if these differences have negative effects on road safety and if they cause problems for international road users.

In this context, the present study focuses on a crucial element of motorways - entry and exit facilities. Here, a foreign road user depends very much on the form of road design that facilitates driving, because he has to orientate, accelerate/decelerate and change lanes at the same time. The study analyses and compares road design features of entry and exit facilities in the different EU countries, such as elements of design, marking, signing and operational regulations. Besides, it will be investigated if the design of exits and entries is relevant to road safety.

Guidelines and other informations were collected from the different EU countries. No information was received from Greece; and in Luxembourg either the French or the German guidelines are used. Furthermore, an investigation was made of international research results. As far as road safety is concerned an accident analysis was made of eight junctions in Germany. The study concentrates on motorways, but also treats 'semi-motorways', or other rural roads. A more extensive treatment of this paragraph is given in Annex VIII to this report (Steinbrecher, 1994).

5.3.2. *Safety and traffic flow*

The most important results concerning road safety gathered from literature (predominant German and Austrian sources) and our own accident analysis (6 junctions with standard and 2 with short entries) are:
- Accidents accumulate on junctions and interchanges.
- Entries are more critical than exits. The number of accidents is between 2 and 4 times higher on entries. The slip roads have less accidents.
- Rear-end accidents dominate (50-60 %).
- All studies show positive effects of parallel speed change lanes of sufficient length. There are 40-45 % less accidents on these entries compared to taper merge entries without parallel speed change lanes.
- The studies show the importance of good road marking and clear sign ing. Foreign road users have more problems in entries with (for them) unsual design than drivers who know the place.

The study of literature concerning traffic flow shows the following:
- There is no common opinion about the best form of exit facilities between the countries, and in the historical development of the countries. Taper diverges and exit facilities with parallel deceleration lanes are applied. The results of research do not show which form allows better traffic flow, or higher capacity. Exits with parallel deceleration lanes cause less disturbance in traffic flow on the mainline carriageway;
- Investigation on entries is concentrated on capacity aspects. All studies - empirical and theoretical models - show great improvement of traffic flow in entries with parallel acceleration lanes.

5.3.3. *Comparison of the guidelines*

The international comparison of the guidelines showed that there are a lot of common design principles: entry and exit facilities are always on the right side in continental countries, recommendation to avoid junctions in curves of the mainline carriageway, cross-sections in slip roads that allow passing a car with breakdown. But also differences in the design parameters were found:
- Parallel speed change lanes are recommended for entries as well as for exits in Germany, the Netherlands, Belgium and Spain. In France and Great Britain they are standard for entries, for exits they are only recommended in the case of two-lane slip roads. In Portugal you find taper merge and diverge in the guidelines, but in practice parallel speed change

lanes are applied. The Danish guidelines in any case show the taper merge and diverge without parallel speed change lane as standard.
- The recommended length of parallel acceleration lanes lies between 200 and 250 m. Including the length of the taper at the end of the speed change lane the values vary between 250 and 350 m. Only in Ireland they appear to be very much longer.
- Taper merges have gaps in the mainline carriageway of 200 m in Great Britain and Denmark and 250 m in Portugal.
- For parallel deceleration lanes, the guidelines recommend a length of 150 to 200 m in the case of one-lane slip roads. Only in Belgium it is much shorter. Including the length of the taper at the start of the speed change lane the values vary between 200 and 250 m.
- Taper diverges have gaps in the mainline carriageway of 100 up to 170 m. The angle of the taper is about 1:25 or 1:30.
- Capacity limits for one-lane entry facilities are mentioned in the guidelines of Germany, France, Great Britain and the Netherlands: 1200 to 1500 veh./hour.
- Some guidelines give values of deceleration for the calculation of the length of deceleration sections. They are 0.8 m/sec^2 for engine braking and 1.5 m/sec^2 for normal braking.

5.3.4. *Marking, signing and operational regulations*

Comparison of road markings showed big differences between the countries:
- The margin of the carriageway is normally marked with a continuous line. In France and Spain, this marking is interrupted to show the possibility of passing this line to reach the emergency lane.
- The separation between speed change lanes and the mainline carriageway is realized by interrupted lines. The length of these lines vary between 1 and 6 m. Normally, the relation between line and gap is about 1:1, only in the Netherlands it is 1:3. In Denmark you find a very different kind of marking in the entries. here, are only three strokes marked behind the nose, in the rest of the taper area there is no separating line between the mainline carriageway and the entry ramp.
- In the Netherlands a special marking of the taper is applied; the whole surface is white, in the other countries there are chevron markings. In France you can find a special marking to facilitate holding distance to the car driving ahead (yellow chevrons) and in Italy there exists a special marking to recommend a speed limit in case of fog.

There are also big differences in vertical signing of exit facilities:
- The standard-colour for signing on motorways is blue, only in Italy you will find green signs, Denmark uses both colours. Seven countries have a numbering-system of junctions and interchanges. In Belgium and Spain, only the exits and entries have numbers, but not the interchanges.
- Normally you will find three or four signs at an exit. In four countries the first sign is erected 1000 m before the exit. Other countries show this sign 1500 m before, in France this distance amounts to 2000 m. In France and Belgium you find additional signs in the median. The content of the signs and the used symbols are very different.
- Speed limits on exit ramps are standard only in France. Beginning with 100 km/h, this sign is followed by corresponding signs of 80 km/h and 60 km/h in the slip road.

- In the Netherlands, a special sign for short entrances 'Korte invoeg-strook' exists, indicating an entry with an acceleration lane of reduced length.
- In Denmark, a special sign at the mainline carriageway 400 m before the entry indicates the following merge of two traffic streams.

Concerning the operational regulations for entry facilities, nearly all countries give priority to the traffic on the mainline carriageway. The emergency lane may be used only for emergency cases. Drivers who did not find a gap in the traffic flow on the mainline carriageway and reach the end of the acceleration lane have to stop. It is not allowed to continue on the emergency lane. Drivers on the mainline carriageway are not obliged to change the lane to facilitate the merging manoeuvre. A complete different situation is to be met in Denmark. There, drivers on the mainline carriageway do not have priority. They have to merge with the entering traffic stream. In Italy, there is a regulation that allows drivers in the case of jam to use the emergency lane for reaching the exit. This is limited for the last 500 m before the exit.

5.3.5. *Conclusions and recommendations*

Looking at the results of the study in an overall view fundamental differences were discovered in the design of entry facilities between Denmark and the other EU-countries that were analysed.
The 'merge-system' in Denmark:
- there is no priority for drivers on the mainline carriageway
- taper merge without parallel speed change lane but with a small angle between the mainline carriageway and the entry
- there is no horizontal marking to separate the mainline carriageway from the entry lane
- there is a special pre-warning sign on the mainline carriageway that indicates the following merge situation.

The 'priority-system' in the other countries:
- priority for drivers on the mainline carriageway
- parallel speed change lane for acceleration
- clear separation between the mainline carriageway and the speed change lane by horizontal marking (modulation 1:1).

Within the two systems there is a coherence between geometric design, marking, vertical signing and operational regulations. From Denmark there are no safety problems reported, the 'merge-system' is also applied in the other Scandinavian countries.

Because of the fundamental importance of these differences in the design of entry facilities we recommend to carry out a study to the two systems. This study should contain analyses of accidents, observations of behaviour and interviews of drivers to allow a comparative assessment of the two systems. Special attention should be paid to foreign motorists. In this context it should be taken into consideration that the 'Motorway Working Group' of the EU-Commission recommends the 'priority-system' for the standardization of road typology in the recent interim report of January 1994.

The comparison of the guidelines in the countries with 'priority-system' showed, that in general the application of parallel speed change lanes is recommended for entries of motorways. The lengths of these acceleration lanes do not have great variation. In any case the guidelines recommend a length of over than 200 m, which seems to be sufficient.

Concerning exits, some countries recommend the taper diverge without parallel deceleration lane. Results of research do not justify a proposal to apply in any case parallel speed change lanes in exits. The most important fact is a sufficient length for deceleration before the driver reaches the minimum curve radius. This is guaranteed in all guidelines.

Concerning the discovered differences in the road markings, it must be taken into consideration that a *clear* marking may be more important for traffic safety than a *uniform* marking in the different countries. The marking has to guide the road user and to warn for difficult situations. In spite of the great deviations in the width of the lines and their lengths, there is one common principle for the separation of a speed change lane from the mainline carriageway: nearly all countries recommend block marking with a relation 1:1 between line and gap.

The big differences in the vertical signing of exits may cause greater problems. Disorientation of drivers provokes dangerous manoeuvres, like stopping at the nose to study maps, or driving back in the ramp. The 'Motorway Working Group' of the EU-Commission hold the opinion that vertical signs can have an important impact on road safety. In an interim report, the group recommends urgently a harmonization of vertical exit signing with a numbering-system and homogeneous symbols. In case of significant differences of the names of the same town in two languages, it is proposed to mention the two names. The 'Motorway Working Group' does not recommend an unique colour for road signing on motorways, because the costs of implementation are high and the effects on road safety could be small.

Because of the generally accepted necessity of harmonized exit signing we recommend to carry out a study to develop principle solutions for the best practice. The study should deal with the kind of panels, location of the signs, contents, symbols, etc.

Finally it should be mentioned that there could be great differences between the guidelines and the reality of design features. Seventeen years after the publication of the German guideline, there still are about 5% exit and entry facilities (ca. 90) with design parameters under the standard of the guideline (too short or missing speed change lanes) in the part of the former Federal Republic of Germany. In the part of the ex-GDR the situation is even more serious. Most of the entries do not have parallel acceleration lanes, because in the former guidelines only taper merges were mentioned. It will take many years to adapt this situation to the guidelines in force now in Germany.

5.3.6. *Reference*

Steinbrecher, J. (1994). *Design features and safety aspects of exit and entry facilities on motorways in the EC.* Aachen: Ingenieursbüro

Steinbrecher. A-94-10. Annex VIII to SWOV-report Safety effects of road design standards.

5.4. Curves in two-lane roads

This section deals with the safety at curves in two-lane roads outside urban areas, and the way the road design standards take this safety aspect into account. A more extensive treatment of this section is given in Annex IX to this study (see Brenac, 1994).

5.4.1. *Safety at bends, research results*

Statistical studies show that the accident rate (accidents per vehicle kilometer) is high for the low values of radius, and decreases when the radius increases.

The alignment in which a curve takes place is very important in the determination of the safety at this curve, according to several studies. The accident rate at small radius bends is very high when the average curvature of the whole alignment is low, but relatively low when the average curvature is important. High accident rates are observed at a bend when it follows a long straight line, when its radius is smaller than the radii of preceding bends and when the number of bends per kilometer is low.

Other external factors have been found as relevant for road safety: severe bend in a steep down grade, short sight-distance (during the approach) on the bend or on the end of the curve.

Some studies show that internal factors (depending on the design of the curve itself) also have important effects on safety, especially at bends having a small or medium average radius of curvature. The main defect is the irregularity of the curvature inside the bend itself, characterized by the presence of locally very small radii compared to the average radius of the curve. The irregularity of the curve has different explanations: ancient road (before the automotive era, circularity and regularity of curves were not so important), bend including several curves of same direction, bend with an excessively long transition curve (clothoid). Concerning this last point, it was also showed that the presence of transition curves (even of a length consistent with standards) deteriorates the perception of the bend and results in an over-estimation of the final radius and of the possible speed. Other internal defects, like poor shoulders, lack of evenness of the pavement in the curve, etc. appear also as accident factors.

5.4.2. *Safety aspects in design standards concerning curves*

Regarding the curves, the most part of national road 'standards', and also the AGR agreement, have a sort of common basis which contains the design speed concept (or other approaching concepts) and rules concerning the minimal values of some main characteristics (especially the radius of curvature). Some countries have introduced complementary rules or approaches, taking into account the actual speeds, and/or defining the conditions of the succession of the different elements of horizontal alignment.

The conventional design speed approach
The differences between countries concerning the minimal characteristics for a same design speed are not so important, and are not critical from a safety point of view. The main difficulty is that the conventional design speed approach is not sufficient to cope with some important safety problems at curves.

The notions of design speed, in spite of the multiplicity of the definitions, are different expressions of the same concept. This concept could either be defined by the objective (the highest constant speed which can be maintained on the overall section in conventional conditions of safety and comfort, and with no limitations due to traffic), or by the means to obtain this objective (the speed determining the minimal characteristics of the alignment - i.e. in conventional conditions of safety and comfort, a vehicle could negotiate the most difficult points of the alignment at this speed).

The problem due to the fact that actual speeds (for example at the 85th percentile of the distribution) are locally much higher than the design speed, even in wet pavement conditions, and that then the minimal characteristics (sight-distances, for example) may be locally inappropriate has been mentioned by other authors.

Regarding especially the safety at bends, one could say that the definition of a minimal radius depending on the design speed is both insufficient and unnecessarily constraining.

Insufficient is that, in the frequent case where design standards do not introduce complementary approaches (to the design speed approach), no explicit rule prevents for example from using a bend with a radius of 140 m after a straight line of 600 m, or after a serie of bends with radii comprised between 300 and 400 m, when the design speed is 60 km/h. And we know that such configurations will contribute to generate accidents.

On the other hand, whatever value is chosen for the design speed, the presence of a bend with a small radius, very inferior to the minimal radius, may be compatible with a good safety, if this curve is preceded and followed closely by curves with comparable or slightly larger radii, themselves introduced by compatible curves. In this sense, the minimal radius associated with the design speed is unnecessarily constraining, from a safety point of view, even if it may be justified from the point of view of the level of service (comfort, time saving).

Introducing the actual speed approach
Some countries have introduced the actual speed in their standards. For example, the design speed is chosen (or modified) for being consistent with an expected journey speed (at the 85th percentile: V85) on a road section, obtained from a model. Or, after the choice of a design speed and the design of the horizontal alignment, the expected speed (V85) is calculated on the different sections; then, the difference between this speed and the design speed is examined, and, if this difference is too large, the design speed or the alignment is modified. The standards of an other country introduce the calculation of this V85 speed at each point of the alignment, but only for the control of sight-distance conditions.

Statistical studies have shown that actual speed is strongly depending on the local characteristics at a given point (mainly: curvature, cross-section, gradient). Then, the calculation of an averaged or journey speed on a section is not satisfying: the actual speed at a point of this section can be much higher, for example.

On the other hand, research results suggest that safety problems due to horizontal alignment inconsistencies can not be completely reduced to a speed question. Even in the same speed conditions before a curve, a severe bend will be more or less expected by the driver, depending on the curves he has encountered on the road before. This will infuence the reaction time of the driver and the correctness of the assessment of the bend characteristics.

To introduce the 'actual speed approach' does not appear sufficient to avoid some alignment inconsistencies resulting in safety problems. Complementary rules, especially those ensuring the consistency between successive elements of the alignment, seem necessary.

Rules on the alignment consistency
Recommendations concerning the consistency of the succession of the different elements of the horizontal alignment are not rare in the road design standards, but they are generally imprecise and not formal. Some countries have introduced more precise rules, giving conditions on the minimal radius of a curve depending on the length of the preceding straight-line, and conditions of compatibility between the radii of two successive curves.

These rules allow certainly to detect and avoid a great number of inconsistencies, and are justified by research results. But their background seems partly empirical, and important differences exist between the rules given by the different standards including this type of approach.

5.4.3. *Signing of curves*

Concerning the treatment of safety problems at curves on existing road, low cost measures are possible when some internal defects (irregularity of curvature, too long clothoids, shoulder or pavement defects) are identified. In this case, slight amendments to the alignment, shoulder reconstruction or pavement treatment are often sufficient. In the other cases, possible low cost treatments are often limited to signing or equipment of the curve.

Beyond the positive influence of signing measures which appears from before-after studies (but frequently biased: regression-to-mean effect), it seems that there is a lack of sufficiently valid results concerning the effects on accidents of signing or equipment of curves (bend sign, chevron boards, elements of delineation on the outer side of the curve, mandatory or advisory speed sign).

Vertical, regularly spaced elements of delineation along the outer side of the curve give informations directly useful for the perceptive task (estimation by the driver of distance, own speed, curvature). At less in the case where the delineation is provided on the entire road section, and not only at curves, perverse effect due to an increase of speeds are possible.

In the national regulations, there are not always formal rules for using or not using signs (bend sign, chevron board) at bends, and when they exist, they are rather different from a country to another, but even inside one country.

5.4.4. *Conclusions and recommendations*

Concerning the safety in the design of curve geometry, in relation with the overall configuration of the horizontal alignment, some main conclusions are summarized here:
(i) The conventional concept of design speed and the associated approach is not sufficient for ensuring the consistency of the horizontal alignment and the safety of curves.
(ii) Introducing, in diverse forms, the expected actual speeds (necessary in other respects, to verify the sight-distance conditions, for example), is positive but not sufficient to complete the conventional approach.
(iii) The introduction of consistency rules concerning the succession of the different elements of the horizontal alignment (radius of a curve following a straight line, compatibility of radii of two near curves) seems necessary from the safety point of view. These rules are present in some national road design standards. But these rules are not homogeneous, and the corresponding knowledge is probably not sufficiently developed.
(iv) The use of complex curves containing a succession of circular curves and transition curves of same direction may generate safety problems and should be avoided. Moreover, the rules for the calculation of the length of transition curves (clothoid), that in the actual situation have a rather negative influence on the perception of the curvature and probably on the safety, should be re-analysed.

Concerning the signing of curve and its effects on safety, it seems that research results are not still sufficient to constitute a solid back-ground for improving the standards. Concerning the use of signing in relation with the difficulty and situation of the bend, the lack of an homogeneous approach is also to be mentioned.

Considering these conclusions, three main proposals could be made:
- It seems desirable that the national road design standards which do not contain explicit rules ensuring the consistency of the succession of the different horizontal alignment elements (minimal radius after a straight line, condition on the radii of two near curves), introduce such rules, of the rules which already exist in national standards of other countries could be used.
- It appears, on the other hand, necessary to complete and to consolidate the knowledge on the relations between the characteristics of the upstream alignment and the safety at the curve, in order to obtain rules with a more solid background, which could be introduced internationally.
- It would be also important to develop the knowledge concerning the effects on safety of the signing of curves, to enable more homogeneous rules through the different European countries.

5.4.5. *Reference*

Brenac, T. (1994). *Curves on two-lane roads.* Salon-de-Provence: INRETS. A-94-11(E). Annex IX to SWOV-report Safety effects of road design standards.

5.5. **Bicycle facilities at intersections**

5.5.1. *Introduction*

Up to now no overview is available of the various standards for bicycle facilities at intersections which exist in EU-countries. A first attempt to provide such an overview was made (see Herrstedt, 1994, Annex X, and Hagenzieker, 1994, Annex XI, for the full report). Besides the fact that standards have usually been formulated only in the language of the specific country concerned, and terminology is not always consistent between countries, even within countries these standards are usually not put together in one single document; instead they can be found as chapters or paragraphs in various documents regarding road standards in general.

5.5.2. *Terminology*

In this paragraph some common terms will be explained, because the use of terms in the guidelines often varies between countries. We have chosen to use these more common terms in a consistent manner according to the definitions as described below.

The term *cycle track* is used here when this cycle facility is separated from the carriageway by a (narrow) dividing verge or by kerbstones ('physical separation'). The term carriageway refers to a road or part of a road to which vehicles - including bicycles in case no specific (compulsory) bicycle tracks are present - have access. The term *cycle lane* refers to a part of the carriageway which is meant to be used by cyclists, and is indicated by markings or painted lines on the road surface ('visual separation'). In some countries, for instance in the Netherlands, within these types of cycle facilities a distinction is made between on the one hand voluntary or recommended use of them by cyclists, and compulsory usage on the other hand. The term *cycle path* is only used for separate cycle tracks with an own alignment (away from roads). The term *cycle route* is used as the general word for cycle paths, for cycle tracks, for cycle lanes, and for roads without any cycle facility that serve as a link in a bicycle network.

A common facility for bicycles at intersections which is described in the various guidelines, is a bent-out cycle track. This term refers to a cycle track that is led from the carriageway at a certain distance before and after an intersection. In Denmark the term 'staggered cycle track' is used for this facility, whereas in Germany and the Netherlands the term 'bent-out cycle track' is used.

The terms *intersection* and *junction* are used interchangeably. In general, though, 'junctions' usually refer to relatively large types of intersection. The term *crossing* is used for that part of the carriageway or intersection used by cyclists for crossing.

5.5.3. *Comparison between countries and conclusions*

Only four EU-countries appear to have specific documentation on the subject of bicycle facilities at intersections: Denmark (see Herrstedt, 1993 for a detailed summary of the Danish guidelines), the Netherlands, United

Kingdom, and Germany. The reason that other EU-countries do not have specific standards for bicycle facilities at intersections is most probably connected to the fact that the bicycle as a mean of transport in these countries is (still) a rare phenomenon. The presented overview, however, might offer some help to those countries that intend to prepare such standards in the future.

Status of the standards

The various 'Highway Codes' in the countries under consideration have compulsory status, and regulate behavioural rules for road users, including cyclists. Also, specific traffic signs to indicate bicycle facilities that can or must be used by cyclists usually have compulsory status, although often additional informative (non-compulsory) signs are used to draw attention to facilities for cyclists. Furthermore, markings on the road to indicate that cyclists can or must use a facility at an intersection, such as the presence or absence of broken lines and cycle symbols painted on the road, are generally of a compulsory nature. However, *design standards for specific bicycle facilities, or 'solutions', at intersections as reviewed here are generally non-compulsory guidelines and recommendations.* Therefore, the terms guidelines and recommendations describe their status better than the term 'standard' might imply.

In general, the guidelines may be departed from, or relaxed, if considered 'appropriate'; these can then be called recommendations. Other guidelines may only be departed from when well motivated. In all countries concerned, procedures exist that must be followed when one wants to depart from the guidelines. In the Netherlands, for example, the various types of 'standards' are explicitly distinguished, and it is indicated in the documents themselves whether described facilities are guidelines or recommendations. However, for the other countries it is not always clear from the documents reviewed whether the described facilities are mere recommendations or more (compulsary) guidelines.

In Denmark and the Netherlands different guidelines and recommendations exist for bicycle facilities at intersections inside built-up areas and outside built-up areas. In Germany mainly all, and in the United Kingdom all guidelines and recommendations apply to both inside and outside built-up areas.

Role of road safety considerations

Although road safety considerations as a criterion for establishing guidelines and recommendations for bicycle facilities at intersections are considered 'important' in all countries, it has to compete with other criteria such as traffic flow and comfort. It is often not clear to what extent road safety played a role: was road safety the most important criterion or did other criteria have priority over safety? So, whereas 'implicitly' road safety is considered an important criterion, the guidelines lack explicit clues that justify specific (elements of) bicycle facilities over others.

In general, it appears that no strong safety evidence is to be found in the guidelines themselves. The guidelines mention no explicit references to research findings. So, even if guidelines state that 'out of road safety considerations' a certain facility is recommended it is often not clear whether this is based on assumptions or on empirical evidence. And if this type of data exists or has been used as a basis for the guidelines, it is still not cited in the guidelines. Although the Danish guidelines themselves do not refer to research findings, it appears that in Denmark the term 'safety' may only be mentioned in the guidelines if research findings have indicated this.

The general impression is that safety assessments of specific cycle facilities at intersections based on accident data are scarce.

Common principles and 'solutions'

Creating *good sight conditions* is mentioned in all guidelines as being an important principle or (safety) criterion. The visibility of the bicycle facilities and the cyclist using them should be guaranteed at sufficient distance before the intersection. This can be accomplished by creating an area that should be kept free from obstacles that can block sight. In Denmark it is generally recommended that at intersections bicycles should be close to motor vehicles, otherwise they will be overseen. In order to attain this a bicycle track often becomes a bicycle lane 25 m before the intersection. Therefore, the bending out of cycle tracks is, in principle, not recommended in Denmark, although exceptions are possible and the Danish guidelines contain recommendations for the bending out of cycle tracks in case these are applied.

At intersections with priority signs, cycle tracks are generally not bent out from the carriageway which has right of way. In this way it is clear for drivers of motor vehicles from the side road that cyclists on the main road have priority. This also holds for turning traffic from the main road. *Bending out is usually recommended at intersections which are not signally controlled, and when it is important that turning motor vehicles from the main road do not interfere immediately with cyclists crossing the side road. This solution is recommended in peculiar outside built-up areas.* It can be accompanied by reversing the priority rules.

In general, *both priority rules and design* are important factors to consider at intersections. *Which priority rules are 'better' or 'safer' is still under discussion.* In Germany, for instance, reversing of priority rules for cyclists at intersections (i.e. that cyclists have to give way to other traffic instead of having priority over other traffic) is, in principle, not recommended, not even outside urban areas. In the Netherlands, however, reversing the priority rules is often recommended outside built-up areas, usually in combination with the application of bent-out cycle tracks at intersections. Reversing priority rules is - under certain conditions - also to be found in the UK-guidelines.

Refuges or *traffic islands* in the road to be crossed allow bicycles to cross in stages. Such facilities are often recommended when cyclists do not have right of way.

The *separation* of cyclists from other traffic, either physically or visually, is a criterion that is also mentioned in all guidelines. Physical separation can be accomplished by applying grade separated junctions or separate cycle paths with their own alignment. Because it is often not possible to create such facilities (e.g. due to lack of space) applying cycle tracks is a common 'solution'. *Streamed cycle tracks* are often recommended when no sufficient room is available to construct bicycle facilities at cross-sections leading to (large, busy) intersections, whereas at the intersection itself possibilities exist to guide bicycles across the intersection separately from other road users. Streamed bicycle tracks begin shortly before the intersection and generally end about 20-50 m behind the intersection. Visual separation refers to cycle lanes which are indicated by painted markings and lines on the carriageway. Whatever solution is chosen, *clear markings and signs* indicating where bicycles can cross the intersection, are in all guidelines considered to be important to increase the safety of cyclists.

The recommendation of certain facilities over others also depends on the *speed and volume of motor vehicles*. Research has indicated that mixing bicycles with motor vehicles at intersections is sometimes even safer than bicycles on cycle tracks. For instance, in most guidelines, mixing bicycles with other traffic is recommended in situations with low speeds and volumes of motor vehicles. Again, clear markings should indicate where cyclists can be encountered. *Weaving lanes* are often recommended when guidance is needed for bicycles to cross the intersection, and when cycle lanes are present at the cross-section leading to the intersection, or when no cycle facilities are present there but guidance is considered necessary. Weaving lanes for bicycles can, for instance, prevent conflicts between right turning motor vehicles and bicycles going straight ahead. To enhance this effect it is often recommended to paint such lanes in a *different colour*, or apply *differentially surfaced* bicycle crossings.

Indirect left turns for cyclists are usually recommended when at the cross-section leading to the intersection cycle tracks are present. Also, if no cycle tracks are present, an indirect left turn is often recommended when a direct left turn is considered too dangerous. It should be realized, however, that indirect left turns should actually be used by cyclists in order for them to be safe. When indirect left turns take a lot of time, and motor vehicle speeds and volumes are low, cyclists often neglect the indirect left turn facilities. In these cases weaving lanes allowing cyclists to turn left directly can be preferred.

Traffic lights can be applied out of safety considerations for bicycles. However, most guidelines recommend in some way or another that, if possible, the need to apply traffic lights should be avoided by adjusting the intersection in any other way. When traffic lights are applied it is usually recommended that traffic light installations are regulated conflict-free, that waiting time is short, that there is a general bicycle phase (i.e. while bicycles are offered green, all other traffic is given a red phase), and that the stage order is friendly for the cyclists. With regard to possible conflicts between bicycles going straight ahead and motor vehicles turning right, an early start can be recommended. Also the guidelines often recommend a separate facility in which cyclists can turn right regardless of the traffic-light regulation.

At intersections with mixed traffic or visual separation, weaving, refuges or special *waiting areas* for cyclists are facilities that are often recommended. In the Netherlands so called 'expanded bicycle streaming lanes' that consist of a separate streaming facility for cyclists in front of the streaming spaces for motorized traffic, and of an accompanying approach cycle lane are recommended at signal controlled intersections. It creates a waiting area for cyclists; they are often accompanied by an early start for cyclists at signal controlled intersections. Experimental application of such facilities in the United Kingdom - although these are not to be found in the guidelines (yet) - show positive results in terms of safety and correct usage.

With respect to *roundabouts* no conclusive findings (from research conducted in Denmark and the Netherlands) exist in order to decide between mixing bicycles with other road users, applying cycle lanes or cycle tracks in the circulation area of roundabouts. The various guidelines, therefore, usually contain recommendations for all types of bicycle facilities as possibilities. Whereas experiences in Denmark and the Netherlands indicate that roundabouts are relatively safe for cyclists as compared to other types of intersections, the United Kingdom-guidelines state that roundabouts pose particular problems for cyclists. The particular design and lay-out of roundabouts, which varies between countries, obviously has implications for the safety of cyclists, and for that reason also for the bicycle facilities that can be recommended.

From the previous paragraphs it becomes apparent that besides common principles and recommendations, also differences are encountered between the guidelines of the various countries. It appears that there are sometimes strong differences in the matter of detail in which the guidelines are described between the various countries, and also the guidelines themselves differ between countries. This probably has to do with the fact that in Germany and the United Kingdom relatively few cyclists are present in traffic, whereas in Denmark and the Netherlands the bicycle is a common mean of transport. This obviously has implications for both the necessity for separate guidelines for bicycle facilities at intersections in the different countries as well as for their contents. For instance, in Germany and the United Kingdom facilities are often shared by cyclists and pedestrians, whereas such facilities are seldom applied in Denmark and the Netherlands. Therefore, guidelines for 'shared use' are to be found in the guidelines of the former two countries but not in the latter two. Also, the application of cycle tracks and cycle lanes varies between countries; for instance, in the United Kingdom cycle tracks are hardly present, whereas in the other countries both types are often present. This is reflected in the guidelines: in Denmark the emphasis in the guidelines is on cycle tracks (cycle lanes are present but no separate guidelines are available for lanes); the Dutch and German guidelines contain recommendations for both types of facility, and the emphasis in the guidelines for the United Kingdom is on cycle lanes and 'shared facilities'.

Finally, the impression is that deviations from the guidelines concerning bicycle facilities at intersections seem to occur frequently. For instance, in Germany a lot of cycle tracks are below the standards and they cause many problems, with pedestrians as well.

Recommendations

For those EU-countries that at present do not have specific guidelines for bicycle facilities at intersections the recommendations as summarized in this report, and in particular *the above mentioned 'common solutions' can be a good starting point for drawing up such guidelines.*

Bicycle facilities at intersections that are supported by evidence for being safe facilities should be the ones to serve as standards. However, as already stated, it appears that no strong safety evidence is to be found in the guidelines themselves. The described common solutions could form the first step towards 'standards', but *systematic 'screening' of the guidelines in connection with existing research findings* is considered a worthwhile exercise in order to provide standards with sound safety implications. Then it will also become clear where there is lack of evidence and need for further research. The impression so far is that research on the safety effects of specific bicycle facilities at intersections is scarce. Therefore, *comparisons between various bicycle facilities by means of accident and behavioural studies*, both within and between countries, are recommended.

5.5.4. *References*

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6. Best practice

6.1. Introduction

It is seldom that the cause of a traffic accident is very simple. More often, a combination of circumstances play a role, in which man, road and vehicle are of importance. The key to a considerable safer road traffic lies in the concept to create an infrastucture that is adapted to the limitations and possibilities of human capacity through proper road design.
Proper road design is crucial to prevent human errors in traffic and less human errors will result in less accidents. Three safety principles have to be applied in a systematic and consistent manner to prevent human errors:
- prevent unintended use of roads and streets, after defining the function of a street;
- prevent large discrepancies in speed, direction and mass at moderate and high speed, i.e. reduce the possibility of serious conflicts in advance; - prevent incertainty amongst road users; i.e. the predictability of the road's course and people's behaviour on the road.

It is to be expected that proper road design, according to these safety principles, on which careful implementation is based using available know-how, could reduce considerable the number of accidents and accident rates compared with the existing situation in Europe.

Road design standards play a vital role in road design in all EU Member States. But some important problems exist in this field, nowadays. First of all, not all countries have road design standards for all types of roads. And as they have so, they are not always applied. When they are applied, some space of interpretation leads to different road design in the same jurisdiction. Further on, as this study indicated very clearly ther is no accordance between various countries on this subject.
The inavailability 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 problems on this continent. As the cross-bordering traffic increase, it becomes even more valid from a road safety point of view for harmonizing road design standards on the level of the European Union. Furtheron, it can be argued to expand this harmonizing to other European countries (e.g. Central and Eastern European Countries) as well.
It is to be expected that a common research programme to support compiling road design standards is more efficient and productive, than when countries on their own have fulfill this task. We recommend that the Commission of the European Union take the initiative to launch such a research programme and co-operates with Member States and interested international organizations.

6.2. Preliminary considerations

Roads are built to perform various functions: flow function, distributor function and access function. Where a combination of functions has to be performed, road safety problems will arise. By making use of a road classification the road user can be made more aware of the main function of a road or street. If the classification system is properly designed and con-

sistently implemented, the road user will behave as desired by the road authority.
This means that road classification systems should be directed more to road users than serving the needs of road administrators.
Road safety is only one of the criteria when designing roads and streets. Unfortunately, road safety is mostly dealt with implicitly. We recommand to enlarge the impact of road safety by making the safety effects more explicitly. One can imagine that a road safety audit or a road safety impact assessment could be very helpful in this respect.

Road design standards should lead to road design governed by: consistency, uniformity, homogenity, predictability. Although rigid road design standards seem to offer the best solution, it has to be accepted that departures from standards are sometimes inevitable due to economic reasons or lack of space. Because departures from standards could have important negative consequences, it is recommended to be as explicit as possible in terms of road safety consequences, when departures from standards are considered.
No departures from design standards should be allowed for the motorway network. From a road safety point of view harmonization of design standards for motorways has to be recommended. For all the other road types, guidelines are to be recommended instead of mandatory standards. International harmonization of these guidelines could be promoted by a sound system of margins allowing designers to depart from certain 'standards', accompanied by a set of well-founded instructions indicating when departures are tolerated and the safety consequences of these departures.
Besides harmonization of design standards it is to be recommended to strive for consistent road traffic rules in Europe.

6.3. Research methods

This study indicates rather clearly, that the road safety justification for road design standards is rarely based on accident analyses, and if these are carried out some doubt may rise about the quality of the methods and techniques used. Measuring the relationship between accidents and road design parameters turned out to be difficult and could be considered as an explanation for our poor knowledge in this field.

Two types of techniques are available for quantifying the relationship between road design parameters and accidents.
The first is the *before and after method.* This method relies on identifying trial sites at which design changes are proposed and comparing data before and after the changes are made. A number of complicating factors have to be taken into account. These are random fluctuations in the basic accident data, the need to control for systematic changes in general accident rates over time, the problem caused by selecting trial sites with high accident rates before treatment (bias by selection) and accident migration (moving road safety problems instead of solving them). Careful design of before and after studies and the use of adequate statistical techniques could overcome these problems and prevent researchers and policy makers from drawing the wrong conclusions.
The second type of study is *so called cross-sectional approach.* In this approach analyses are made on accident data, traffic flow data and geometric data, combined with information about risk-influencing factors

(weather, alcohol use, etc.) from a wide range of sites of a particular type. From these analyses estimates are derived of the relations between the risk and the severity of accidents and the geometric design variables. Statistical modeling techniques (in the hands of experts) will result in correct conclusions.

It is advised to add the results of behavioural studies to these accident studies. Especially field studies, in which behaviour is observed in real traffic conditions, could explain the results of accident studies. Moreover, behavioural studies are recommended to inform the road designer whether his intentions with a specific road design became reality. So, behavioural studies (field studies, laboratory studies and questionnaire and interview surveys) are of importance for researchers and road designers to understand the response of road users to changed road characteristics.

6.4. International and national road design standards

Road design standards and traffic regulations are most of the time a matter of national interest. As traffic tends to cross borders international regulations and standards are nowadays indispensable and a certain degree of harmonization is necessary. This would benefit the road user and will have a positive effect on road safety.

The most important organization with respect to road design standards is the European Union. It is the only international organization that can enforce by legal means the decisions taken. In the Maastricht treaty on the European Union new fields of competence were attributed to the Union. A new provision on road safety was inserted in article 75 and a whole new chapter on trans-european networks (article 129) was added. As the European Union will be a prime investor in infrastructure, it is rational that decisions are coordinated with the Member States. The planning and quality of infrastructural investments is a matter of both European and national interest, in particular for the so-called Trans European Road Network (TERN).
The United Nations' Economic Commission for Europe has issued the European Agreement on Main International Traffic Artereies (usually called AGR). It established the E-road network. The AGR has annexes that among others provide road design standards. The main finding is that AGR is not strict enough. It gives very few 'standards' and recommendations are formulated unprecisely. Moreover, from a road safety point of view, some remarks could be made about the clarity for the road user of this E-road network.
Reference should be made to work done by the European Committee for Standardization CEN. A committee that is of interest for road design standards is Technical Committee 226, which deals with European standards on road equipment. CEN is setting functional requirements.
Other international bodies like OECD, PRI, FERSI, IRF, PIARC, AIT/FIA, ECMT are known for all the work in information exchange, research, policy implementation etc.

All twelve Member States of the European Union have or use national road design standards. In Greece and Luxemburg no specific standards are existing; both countries use standards of other countries. Greece is developing its own standards.

The other ten countries all have standards for rural roads; in some countries they are mandatory, in some others not. Only five countries have standards for urban roads, which are non-mandatory in four cases, but which are mandatory in Italy. Some standards (Portugal and the United Kingdom) deal explicitely with the problem of relaxations or departures from standards.

It is not well-documented when and how departures of standards influence the safety quality of a road design. It can be recommended to look for the best practice concerning procedures of relaxations or departures from standards, whether they are mandatory or not. This indicates a research programme, when a lack of knowledge makes it impossible to come to any assessment about relaxation or departure.

6.5. Detailed studies

6.5.1. *Cross-section design*

Motorway design has to meet high design standards, because on these roads high speeds (100 - 130 km/h) are allowed and because the road users expect continuity in design characteristics. Sub-standard motorways or non-motorway divided roads with motorway characteristics have relatively high accident rates; for road safety reasons, they should not be built. Four lane undivided roads should be avoided in rural areas. No doubts exist about the effectiveness of medians: these reduce accident frequencies, especially those related to overtaking.

Research results indicate to doubt the validity of the until now undoubted supposition 'the wider the road, the safer'. It is recommended to undertake European research to find out an optimum for lane width and pavement width for different types of roads. Most EU countries use for motorways a *lane width* of 3.75 m. A width if 3.25 m is rarely used and only for a design speed of 90 km/h. Widening a motorway lane over 3.5 m does not result in safety benefits, so a lane width of 3.5 m can be recommended. For urban motorways the safety effects of 3.25 m lane width should be investigated to determine safety consequences.
Outer paved *shoulder width* (emergency stopping lane for motorways) varies considerably, from 2.0 to 3.75 m. There is a total disagreement in Europe on the recommended width of the outer paved shoulder. However, from a road safety point of view a minimum width of 3 m could be recommended.
Pavement width results from lane width and shoulder width: a minimum width of 9.5 m for one carriageway of 2x2 lane motorways. Because of maintenance requirements a pavement width of 11.5 - 12.0 m is recommended in some countries. The safety effect of this approach is recommended to be investigated.
Two lane two way rural roads have considerably different dimensions for the width of lanes and shoulders.

6.5.2. *Medians, shoulders and verges*

A safe design of the verges is intended to prevent occupants of vehicles that leave the road from (serious) injury. With respect to the design of verges three basic design strategies can be distinguished: design an obstacle free zone; allow single obstacles but design them in such a way that they can not endanger car occupants; and finally, design a full protected zone (by means of a crash barrier). An obstacle free zone is to be recommended. Little research has been done on obstacle free zones. A Dutch study concludes to widths varying from 10 m for motorways to 4.5 m for single carriageway roads with a design speed of 80 km/h. An international study is recommended.

The design of medians for motorways protected with crash barriers is well established. Based on research two cross-sections of a median with crash barriers is illustrated in Figure.
The distance between the painted marking of the outer lane and the crash barrier in a shoulder is the sum of the dimensions of the emergency lane and the distance to the crash barrier.

For rural undivided roads - which have higher accident rates than motorways - it is not recommended to provide the verges with crash barriers in view of the risk of frontal collisions with rebounding vehicles.

6.5.3. *Exit and entry facilities on motorways*

Entries of motorways are more critical than exits: the number of accidents at entries is 2 to 4 times higher than at exits. Parallel speed change lanes of sufficient length have positive effects on road safety. More accidents occur on taper merge entries without parallel speed change lanes. Studies show the importance of good road marking and clear signing, especially for foreign road users. The recommended length of acceleration lanes lies between 200 and 250 m. Including the length of the taper at the end of the speed change lane the values vary between 250 and 350 m.

There is no common opinion between countries about the best form of *exit facilities*. Taper diverges and exit facilities with parallel deceleration lanes are applied in Europe and research results do not indicate which is to be preferred, from a road safety point of view. For parallel deceleration lanes guidelines recommend a length of 150 to 200 m in the case of a one way slip road.

There are big differences in vertical signing of exit facilities. The standard colour for signing on motorways is blue, only in Italy you will find green. A limited amount of countries have a numbering system of junctions and interchanges. The number of signs per exit varies between three and four signs. Concerning the operational regulations for entry facilities, nearly all countries give priority to the mainline carriageway; an exception is Denmark where drivers on the main carriageway have to merge with the entering traffic stream.

The great differences in the vertical signing of exits may cause greater problems than differences between road markings: possible disorientation provokes dangerous driving. A harmonization of vertical exit signing is to be recommended.

Looking at the design of entry facilities a fundamental different approach can be discovered between Denmark and other Member States. Because no differences in safety effects are known it is recommended to carry out a study to compare the Danish 'merge-system' with the 'priority-system', used in other countries in the EU.

Concerning exits, some countries recommend the taper diverge without parallel deceleration lanes. No research results are available to justify in any case parallel speed change lanes in exits. The most important factor is a sufficient length for deceleration before the driver reaches the minimum curve radius.

Comparison of road markings shows big differences between the different member states of the European Union. However, a common opinion exists about the separation of speed change lanes and the main carriageways: nearly all countries recommend block marking with a relation 1:1 between line and gap.

6.5.4. *Curves in two-lane roads*

Statistical studies show that the accident rate for (horizontal) curves is higher than for straight stretches of roads and in curves accident rates are relatively high for the low values of radius, and decreases when the radius increases. The accident rate at small radius bends is very high when the average curvature of the whole alignment is low. Some studies show that irregularities of the curvature itself (locally very small radii compared to the average radius, bend with an excessively long transition curve, poor shoulders, lack of evenness in the curve) influence road safety negatively.

In road design standards the common basis for curves is the concept of design speed leading to minimal values for some main design characteristics. Introducing the (expected) actual approach speed is of benefit but is not sufficient to complete the conventional approach. Some countries have introduced complementary rules or approaches taking into account the actual speeds and the succession of the different elements of horizontal alignment. A large variety of approaches for the design of curves are found in national design standards.
Research results suggest that the approaches using design speed or actual speed appear not sufficient to avoid some alignment inconsistencies. Generally speaking, either large or tight curvature is recommended and curves in a middle range of curvatures have to be avoided. Complementary rules, especially those ensuring the consistency between successive elements of the alignment leading to better predictability for road users, seem necessary. Of importance in this respect is the relationship between the minimum radius of a curve and the length of the preceding straight-line and the compatibility between the radii of two successive curves. These consistency rules are present in some national road design standards, but these rules are not comparable. Moreover, the necessary knowledge for this approach seems not sufficiently developed. For the design of new roads, and especially for curves, it is advisable to use the concept of consistency of the succession of the different horizontal alignment elements.

For existing roads it is necessary to pay more attention to the signing of curves. From a European perspective it is recommended to harmonize signing of curves, especially on rural roads, between the different countries. A follow up study is recommended. This study should pay attention to human behaviour (detection of curves, perception of curvature etc.) and road accidents in relation to signing (horizontal and vertical) and other equipment of curves.

6.5.5. *Bicycle facilities at intersections*

Up to now no overview is available of the various standards for bicycle facilities at intersections which exist in EU-countries. Only four countries appear to have specific information: Denmark, Germany, the Netherlands and the United Kingdom. The design standards for specific bicycle facilities at intersections are generally non-compulsory guidelines and recommendations. The terms guidelines and recommendations describe their status better than the term standard might imply. Although road safety considerations as a criterion for establishing guidelines and recommendations for bicycle facilities at intersections are considered 'important' in all countries, they have to compete with other criteria. It is often not clear to what extent road safety has played a role. In general, it appears that no strong evidence is to be found in the guidelines themselves. Furthermore, the general impression is that safety assessments of specific cycle facilities based on accident data are scarce. However, some common principles and solutions can be formulated as a good starting point for drawing up guidelines.

Creating *good sight conditions* is mentioned in all guidelines as being an important principle or (safety) criterion. In order to attain this it is recommended that when approaching intersections bicycles should be close to motor vehicles, otherwise they will easily be overseen: a bicycle track (separated from the carriageway by a verge or by kerbstones) is often turned into a cycle lane (visual seperation only, indicated for example by markings) at about 25 m before the intersection. Weaving lanes can prevent conflicts between right turning motor vehicles and bicycles going straight ahead. To enhance this effect it is often recommended to paint such lanes or to use different surfaces.

The *separation* of cyclists from other traffic, either physically or visually, is a second criterion mentioned in all guidelines. Mixing bicycles and other traffic is recommended in situations with low speeds and volumes of motor vehicles. In case of separation, physical separation has to be preferred. When it is not possible, visual separation using clear markings and signs, must indicate clearly where cyclists can cross the intersection.

Both *design and priority rules* are important factors to be considered at intersections. Which priority rules are better or safer is still under discussion. Different countries recommend different solutions, dependent on design characteristics (bending out a cycle-track or not, inside or outside built-up areas). Recommendations also depend on the speed and volume of motor vehicles.

At intersections with priority signs, cycle tracks are generally not bent out from the carriageway which has right of way. Bending out is usually recommended at intersections which are not signal controlled, and when it is important that turning motor vehicles from the main road do not interfere immediately with cyclists crossing the side road.
Refuges or traffic islands in the road to be crossed allow cyclists to cross in stages. Such facilities are often recommended when cyclistst do not

have right of way. Left turns for cyclists (in right hand traffic) are considered a dangerous manoeuvre. Indirect left turns are often recommended, but then these indirect left turns should actually be used by cyclists. When possible, traffic lights should be avoided by adjusting the intersection in another way. When traffic lights are applied conflictfree phases for cyclists are recommended. Roundabouts are relatively safe compared to other types of intersections, also for cyclists. This seems to be the case in Denmark and the Netherlands, in the UK particular problems on roundabouts are mentioned. Physical separation on roundabouts is to be recommended, when high volumes of bicycles and motor vehicles are present.

The impression so far is that research on the safety effects of specific bicycle facilities at intersections is scarce. Therefore, comparisons between various bicycle facilities by means of accident analysis and behavioural studies, both within and between countries, are recommended.