Safety effects of road design in Europe

Paper presented at 'The European Market for Infrastructural Projects', Rotterdam, September 24-26, 1996

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1. Introduction

Until now, road design standards and traffic regulations are a matter of national interest in Europe. As geographical, historical, psychological conditions differ, it is to be understood that road design is treated on a national level. But traffic tends to cross borders in Europe and with the increase of international traffic, international regulations and standards are becoming more expedient. From a road user perspective harmonization of design standards and traffic regulation is, and will be, of interest: more comfort for obvious reasons. However, a transition process from national standards towards international standards will be a very complex, time consuming and costly process. Due to its complexity rational decisions are required, based on cost-effectiveness considerations, but it is to be expected that political arguments will enter the arena as well.

The most important organization in this respect is the European Union. This has to do with its potential, because this international organization can enforce by legal means the decisions taken. 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. Given the discussions about 'subsidiarity' in the European Union the Commission started to stimulate exchange of knowledge and commissioned several studies to identify the main points of interest, also in the field of road safety and infrastructure design. Later, the European Union can (and will) evolve towards the principle actor in this field, when Member States delegate power to the Union and the Union can (and will) enforce that power with legal means.

In the field of infrastructure, the EU is establishing a network, called the Trans European Road Network (TERN). This network is formally approved by the Council of the EU (CEE, 1993), but the TERN will have to be approved once more along the newly introduced cooperation 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 for TERN and one of those working groups START (Standardisation of Road Typology) elaborates road design standards (CEE, 1994).

This contribution deals with the result of several studies related to the theme of the relationship between road design and road safety. The title of the first study is: 'Safety effects of road design standards' (Ruyters, Slop & Wegman [Eds.], 1994). The following aims for this study have been distinguished:

- 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 and (b) drawing an inventory of national road design standards and the underlying knowledge;
- analysing the role safety arguments have played when road design standards were compiled;

- drawing a 'best practice' for road design standards in which considerations, background information and assumptions concerning road safety have been made explicit.

A first follow-up of this study was prepared by SWOV for the Working Party 'Infrastructure' of the so-called High-Level Group: 'Recommended safety measures for application on interurban roads in the short term' (Slop & Catshoek, 1995). This report contains ten road safety measures and some rough indications of their cost-effectiveness, which could be applied on non-motorway interurban roads in Europe in the short term.

The second study deals with 'best practice' in the field of road design as well. DGVII from the European Commission invited the European Road Safety Federation to prepare and promote 'technical guides' on road safety. The ERSF invited several experts to prepare a first technical guide on 'Road Safety for Interurban Roads' (ERSF, 1996). This document contains practical information for the road designer.

Another interesting study (Wegman, et al., 1994) to be mentioned here deals with tools and procedures for a 'Road Safety Impact Assessment including a road safety audit' (RIA).

As a follow-up of the 'road design standard study' a new study has started mid 1997: *SAFESTAR (Safety standards for road design and redesign).* This study is part of the EU 4th Framework Programme. The task is: "To develop safety standards for highway design and redesign on all classes of road, including tunnels and bridges, taking account of the proposals for technical standards made in the TERN-report".

2. Preliminary considerations for road design

Each year accidents are the cause of about 45,000 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.

All countries have been taking and still take such kind of measures as legislation followed by police enforcement, improvement of road infrastructure and 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 play a role, in which man, road and vehicle are of importance. Research reports from different countries have concluded that about 95% of accidents are due to human error, 30% result from faults in road design and 10% are the result of mechanical defects. One conclusion that is sometimes drawn from this is that education (information, police enforcement, training) is the most important way of preventing accidents. This conclusion is erroneous and researchers have warned often enough about drawing such a conclusion. Is it not the case that road improvements, for instance, are intended to prevent human error? Information about the 'single' cause of accidents does not logically lead to a conclusion about the most effective way of preventing accidents, not counting the cost of measures. It is also possible to draw erroneous conclusions if one relies on police reports in which the question of guilt is settled. One of the people involved in the accident has always violated the law in some way. However, this does not say anything about the most effective way of preventing an accident.

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 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 lead to less accidents. Three safety principles have to be applied in systematic and consistent manner to prevent human errors:

- *prevent unintended use of roads and streets*, after having defined the function of a street; flow or through 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 roads course and peoples behaviour on the road.

This approach will lead logically to a road network with three functional road categories: *roads and streets with a flow function, a distributor function or an access function.* The three functions are of equal importance. Therefor, 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 can be distinguished within one road category. The point is to keep the function of the road clear to road users, despite differences in design.

It is to be expected that proper road design, according to these 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 regulation).

Most European road design standards give definite instructions for the layout of the various elements of a road. 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 with traffic flow, accessibility, environment, costs, etc. Often it is not even clear to what extent a certain standard was based upon 'facts' and to what extent upon assumptions.

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. *This conclusion requires to first harmonize the underlying assumptions.*

More generally speaking, when designing a road frequent use is being made of figures and relations, but not all figures and relations used are equally firm; a destinction has to be made between factual and assumed figures and relations. It is essential to have knowledge about this, when talking about harmonization.

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. A practical possibility might be to indicate margins around certain values, which may be used by the designer 'in emergency'. As international harmonization is concerned, the question how to treat departures from standards have to be raised repeatedly. This requires a set of well-founded instructions indicating when departures are tolerated

3. International and national road design standards in Europe: an overview

Road design standards play a vital role in road design in all EU Member States. But some important problems exist in this field nowadays (Ruyters, et al., 1994). First of all Member States (for twelve Member States material has been collected, which means that information on the three new Member States - Austria, Finland and Sweden - is not available) do have their own national standard.

Table 1 (Ruyters, 1994a) gives a schematic representation of all international agreements or other cooperation forms, which are of relevance for road design and traffic operation (in chronological order). Besides the 1968 Conventions on Road Traffic and on Road Signs and Signals as supplemented by the 1971 European Agreements and the 1973 Protocol on Road markings, the European Agreement on Main International Traffic Arteries (AGR) is of importance. The main text defines and establishes the international E-road network. In one of the Annexes to AGR information can be found on classification of international roads and on geometric characteristics: general considerations, horizontal and vertical alignment, cross-section, intersections and 'equipment, environment and landscaping, maintenance'.

When comparing the AGR, Annex II of 1975 and 1988, the latter one is much looser, unprecise. Values given are less restrictive, strong limits are fewer. It seems that in this way, the annex can respond better to the diversity of national norms. A very weak point seems to be the classification: the category of motorways is clearly defined. Express roads not. The ordinary roads (in the E-road network!) are left almost without any values or standards.

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
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

Table 1. *Schematic representation of all international agreements or other cooperation forms, which are of relevance for road design and traffic operation (in chronological order).*

Table 2 gives one example of the situation in Europe based on information collected by O'Cinnéide (O'Cinnéide et al., 1993). For different design speeds the values are given per country for the minimum horizontal curve radius. Not for harmonization-sake, but for road safety reasons it is to be recommended to find out whether some form of agreement could be reached in Europe on design standards. A common research programme to support compiling road design standards is recommended because it is expected to be more effective and productive.

Besides the problem of different design standards for different European countries, we are confronted with different philosophies regarding the application of standards, when and how to depart and what are the safety consequences of these departures from design standards (Ruyters, 1994b). *This conclusion leads to the recommendation to look for the best practice concerning procedures of relaxations or departures from standards, whether they are mandatory or not. Secondly, this indicates a research programme in which safety consequences of design standards and departures from these standards are made as explicit as possible.*

	Minimum horizontal curve radius (m)												
Design speed	*140*	*130*	*120*	*110*	*100*	*90*	*85*	*80*	*70*	*60*	*50*	*40*	*30*
AGR	1000		650		450			240		120			
Austria	1000		700		450			250	180	125	80	45	
Belgium			750			350				130			
Denmark			872		492			265		130		50	
Finland			1100		650			350		170	110		
France			665		425			240		120			
Germany			800		500	380		280	200	135			
Greece			500		350			200	140		75	50	30
Iceland					450	350		250		125	80		
Ireland			600		400			240		130		50	
Italy	965		667		440			260		120		40	
Netherlands			750		450*	350		260*	185	130*	85		
Norway					430	320		230	160	110			
Portugal			700		450			230	170	120	80	40	
Spain	1000		650		450			250					
Sweden				625	500		350				160		
Switzerland		780	650		420			240		120			
United Kingdom			720		510		360		255	180	127		
T.E.M.	1000		650		450			240					

Note: Above values represent 'Absolute Minimum' for UK and 'Minimum' for all other countries.
* Non-Motorway Design Speeds (NL)

Table 2. *For different design speeds the values are given per country for the minimum horizontal curve radius.*

4. Recommended safety measures for application on interurban roads in the short term

About 90% of all casualties on non-motorway roads outside built-up areas can be connected with just four kinds of manoeuvre: getting off the road (35%), collisions with intersecting vehicles (20%), head-on collisions (20%) and rear-end collisions (20%). A recent study (Slop & Catshoek, 1995) has resulted in the selection of ten countermeasures. By a questionnaire representatives of EU Member States were invited to compile relevant countermeasures. Based on knowledge found in the literature and group discussions with several experts all possible measures have been scored on a cost-effectiveness scale. Three groups of countermeasures can be formed, with different degrees of cost-effectiveness; a high cost-effectiveness means that the money is well spent. There is also a group for which no cost-effectiveness could be established.

No cost-effectiveness to be established
1. Road, traffic and accident data collection
2. Road safety inspection
3a. Black spot analysis
4. Road safety impact assessment (RIA)

Relatively high cost-effectiveness
3b. Black spot treatment
6a. Building small roundabouts instead of intersections
9. Consistency in the signing and marking of (sharp) bends
10a. Alternative routing of slow traffic without building parallel link

Medium cost-effectiveness
5. Traffic calming in thoroughfares through small towns and villages
7. Safety barriers at hazardous locations

Relatively low cost-effectiveness
6b. Building large roundabouts instead of intersections
8. Restricting the possibilities of overtaking
10b. Alternative routing of slow traffic with the building of parallel links

The proposals in this report are of a general nature. The actual opportunities for implementation may be different in the various countries. In some countries, the implementation could be promoted by legal measures, other countries may prefer guidelines that are not compulsory.

However, the design of the infrastructural measures themselves should diverge as least as possible. In view of this, designers in the various countries should all have the same knowledge of current common opinions about proper road design. The impression prevails that improvement of the situation is possible. To this end, the report and accordingly the EU-Working Party, concluded that it would be useful to establish European technical guidelines for the safety of interurban roads, regarding their construction, improvement, and maintenance and signing system.

5. INTERSAFE: Road Safety for Interurban Roads

National standards for geometric road design, including the redesign of existing roads, differ largely in the various countries of Europe, as has been indicated before. Often, the upper (or lower) limits of values that are recommended or permitted do not match; they are sometimes even contradictonary. It also happens that standards for a certain road design element exist in some countries but not in others. Furthermore, standards may be mandatory or just have the character of a guideline.

As a result of this, the actual layout of the roads and the way they are used diverge considerably between countries, and even within countries. Without changing any official standards much can be done in the field of harmonizing the practice of road design by just making the flexibility provided within the existing standards. In a smaller number of cases, mandatory standards will have to be changed to arrive at harmony.

Road safety is of growing importance and concern. Therefore, any action towards harmonizing the current practice by selecting certain design values as the optimal ones - or even as the only ones to be used - should be inspired by road safety motives only. A document was compiled with the latest knowledge in this field (ERSF, 1996)

In this technical guide on design of interurban roads an attempt has been made to provide the optimal values referred to above, together with reasoning behind their selection. *The result is a review of ready-for-use knowledge suitable for designing and redesigning roads with special respect to road safety*. The report covers: basic assumptions, alignment, cross-section and intersections. In an annex signs, markings and roadside equipment are dealt with.

6. Road Safety Impact Assessment RIA

Road safety is a quality aspect of road traffic and this aspect has to be balanced with aspects like: level of service, access for destinations, environmental impact, costs etc., when it comes to decisions in what infrastructural projects to invest. In decision making on infrastructural projects road safety arguments have to be considered as explicit as possible in the planning phase already. An instrument has beeen developed with this aim: Road Safety Impact Assessment RIA (Wegman, et al., 1994). RIAs could be made on a more strategic level and on an individual project or scheme level. For both levels different tools are developed.

On a *strategic level*, the report suggests to assess safety consequences of changes (redistributions) of traffic over a road network due to infrastructural projects (new roads, new lay out of roads) by using a *scenario technique*. This technique uses the fact that different categories of roads turn out to have different road safety records dependent on traffic volumes. By modelling road type, values of relevant safety indicators and traffic volumes road safety impacts can be calculated of different alternatives. A proposal has been developed for the content of (the first phase of) a RIA.

Secondly, on a *project level*, we suggest to use an *audit technique* to make as explicit as possible the safety consequences of certain choices in the detailed planning and the design process and to optimize a road design. The primary objective of using an audit technique is to ensure that road safety is optimally incorporated during the design and realisation phase of infrastructure projects. Independency of auditors is considered of great importance. Different checklists have to be developed in a follow up study.

It is recommend to use the results of this study as a first draft for a RIA and to gain experiences with this tool for EU projects on a voluntary basis, before making a RIA compulsory. An EU-cooperative effort may be considered to reach some sort of agreement on the specifications of RIAs and to create a database with (EU)RIA-methodology and -results. When these results are satisfying, we recommend to integrate the procedure for a RIA in existing procedures for Environmental Impact Assessment (EIA), as indicated in EC Directive 85/337, and not to initiate new procedures for a RIA. This recommendation is based on the positive experiences with EIAs. *By integration of the EIA and RIA procedures, we expect an improved quality of the decision process, without a possible drawback of more time consuming of these procedures*. Of course, Member States could decide to use more stricter regulations.

7. SAFESTAR: Safety standards for road design and redesign; an introduction

As mentioned before in order to obtain a structurally safe traffic system, road design should be optimally adapted to the human capabilities and limitations. In order to enhance road safety in Europe continued improvement of road design standards is required. In fact, it has been estimated that engineering improvements on the road have been one of the main factors behind the reduction in casualties on the roads of the EU countries in recent years. The objective of a new research programme SAFESTAR (SWOV, 1995) is to capitalize on this work, to fill in some existing gaps in our knowledge and to develop appropriate standards for road infrastructure. These standards would help to install good practice on all types of road throughout EU countries.

Final technical standards, or even proposals for these, cannot be produced from a safety perspective only. Therefore, the outcome of this research will be safety arguments for selecting certain design elements or for recommending certain dimensions. However, safety is usually among the criteria that are allowed for too implicitly: at every step in the design process, the designer is supposed to take decisions with safety in mind. Thus, at the end of the process, it is difficult to judge to which extent safety has been taken into account.

In general, safety can be considered at four different levels:
- safety achieved through specific attention paid during the detailed road design process;
- safety achieved through adherence to norms and standards of road design;
- the level of safety that can be achieved through road classification;
- the (explicit) amount of safety offered by the conceptual transport system satisfying the need for mobility.

The last three issues ask for a system of standards to be proposed as a result of this SAFESTAR-project. This system could at least be used as a reference, and at most as a official international agreement. Carrying out the project at the Community level will make it possible to promote uniformity in the best practice of safety standards throughout the EU countries, which is important in the efforts of fulfilling the Community policies, in particular the common transport policy.

According to the title of one of the research tasks is, as indicated by the European Commission in the Framework Programme IV, Field VI: Transport, Section 7: Road Transport, Research Task 7.2/13: "Development of safety standards for highway design and redesign of all classes of road, including tunnels and bridges, taking account of the proposals for technical standards made in the TERN report".

By analysing the START report a research consortium, comprising nine research institutes, put together a programme, with eight work packages. To introduce this research programme shortly, the following information can be given on the different workpackages.

Workpackage 1: Motorways: emergency lanes, shoulders and verges
Objective: based on an (in-depth) analysis of those accidents on (a selection of) TERN motorways that are related to the use of emergency lanes and/or to vehicles leaving the road, production of an accident typology and preparation of a first proposal how to prevent these types of accident/or the severity of the consequences of these accidents.

Workpackage 2: Tunnels on motorways
Objective: to guarantee safety in longer tunnels with entries and exits, it is necessary to assess to what extent it is acceptable to deviate from standard motorway design criteria, and what additional criteria should be used.

Workpackage 3: Express roads
Objective: to produce safety standards for this road type, which have a poor accident record often explained from their ambiguous character.

Workpackage 4: Cross-section of rural roads
Objective: to find out the safety advantages of different kinds of rural single carriageway TERN cross-sections in different conditions.

Workpackage 5: Design of curves in rural roads
Objective: the development of models to predict speed profiles in TERN two-lane single carriageway roads as a way to detect speed inconsistencies in curves and to develop an method to detect road geometric design inconsistencies which create speed patterns and manoeuvres leading to accidents.

Workpackage 6: Marking of bends in rural roads
Objective: by means of an experimental study testing different marking principles, i e. by vertical signs and/or horizontal markings, to develop an efficient concept for the marking of bends in various danger categories.

Workpackage 7: Junction design
Objective: to establish basic knowledge and relationships between junction and traffic characteristics on the one hand, and safety indicators on the other hand. This knowledge should form the basis for establishing effective safety standards for junctions in the European countries. Special attention will be given to roundabouts and signalized junctions.

Workpackage 8: Safety audits
Objective: to establish tools and procedures (strategical and practical) for a Road Safety Impact Assessment (RIA), including road safety audits, to be applied for new road schemes in the EU countries.

The research programme will take 24 months. Twelve months after the start of the project partial reports will be produced and will be discussed with all partners, representatives of the European Commission, representatives of the START working group and from national road authorities. Such a meeting is foreseen as well, short before finalizing the project, in which an attempt to integrate all research results will be very crucial.

8. Conclusions and recommendations

Proper road design is crucial to prevent human errors in traffic and less human errors will result in less accidents. It is to be expected that proper road design, according to three safety principles, could reduce considerably the number of accidents and accident rates compared with the existing situation in Europe. These three safety principles are:

- prevent unintended use of roads - after having defined the function of each road;
- prevent large discrepancies in speed direction and mass at moderate and high speed;
- prevent uncertainty amongst road users.

Road design standards play a vital role in road design in all Member States, but major problems exist in this field: not all countries have road design standards for all types of roads, road authorities do not always apply their standards, some space for interpretation is possible, road safety arguments are dealt with rather implicitly in design standards and there is no accordance between various countries. Underlying to this, the relationships between road features and safety are not always well understood quantitatively. *The unavailability and non-accordance of road design standards for the road network in Europe increase risks and therefore contribute to the actual size of the problem on this continent.* As the cross-bordering traffic increases, it becomes even more valid from a road safety point of view to harmonize road design standards on the level of the European Union and to expand this harmonization to other countries (e.g. Central and Eastern European Countries) as well.

A lot of knowledge is available and it is recommended to draft and update 'best practices reports' about relevant topics and to disseminate this knowledge to road designers and road safety practicionners all over Europe. Member States of the European Union (and from Central and Eastern European Countries) could co-operate in this field and the European Commission (DG I PHARE/TACIS) and DG VII (Transport) are encouraged to stimulate this development.

It is recommended to gain experiences with Road Safety Impact Assessessments (incl. road safety audits) for EU-projects on a voluntary basis. When the results are satisfying, we recommend to integrate the procedure for a RIA in existing procedures for Environmental Impact Assessment EIA. By integrating both procedures an improved quality will be the result of the decision process on investments in new and existing road infrastructure.

The European Commission has taken the initiative to launch a research programme in the field of road design (standards) and road safety. This valuable initiative will result in more international co-operation in the field of road design and road safety, as can be seen in the SAFESTAR project, and could be considered as a small bottom-up step towards harmonizing road design practices and road design standards in Europe, in which road safety considerations are dealt with more explicitly. This would most probably result in safer European roads.

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