European Co-operation in the Field of Scientific and Technical Research

COST 331

Requirements for Horizontal Road Marking

Final Report of the Action

European Commission
Directorate General Transport

LEGAL NOTICE

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Chapter 1. Introduction

In the 15 Member States of the European Union, 45,000 people are killed each year in traffic accidents; that means 900 every week, and 1.6 million are injured resulting in 0.5 million admissions to hospitals, of which 25% result in invalidity. Road traffic accounts for some 95% of all persons killed in transport accidents.

On the basis of current figures and without changes in policies, practices and behaviour 1 in 80 people now living in the EU will die as a result of a road accident and about 1 in 3 of the Union's citizens will need hospital treatment in their lifetime because of injuries sustained in road accidents. The pain and anguish caused by these realities is obviously beyond measurement, but there is a huge economic price to be paid as well.

The economic costs arising from medical expenses, police and emergency services, damage to property and lost economic output of the killed and injured persons amount to about EURO 45 billion a year, something like 0.75% to 1% of the GDP. The average economic cost of each person killed in traffic accidents amounts to EURO 1 million. Other, apparently more realistic calculations estimate the cost of road accidents at least at EURO 100 billion annually and the total socio-economic costs exceeding EURO 160 billion.

This unaffordable situation, in mere economic terms not to mention unmeasurable human suffering, leads more and more to growing acceptance that a wide range of strategies is needed to address the problem. *The traffic system has to adapt to the needs, mistakes and vulnerabilities of road users rather than the other way around*.

It is assumed by traffic experts that road casualties are caused by failures in the traffic system as a whole (which includes road users' decisions and actions, infrastructure and vehicles) and can only be reduced effectively by adopting a systematic approach to this problem. Road safety is a complex and interdisciplinary subject in which the various factors (driver, car, infrastructure) play an important role and interact to a significant degree.

Later trends in road safety look, more and more, towards *Low Cost road engineering Measures* (LCM), such as minor changes in junction operation, road lay-out, lighting, signs and markings which can be implemented quickly and make significant contributions to road safety.

Within the above mentioned set of LCM, those concerning road signing in general (and in particular, road markings), have been traditionally considered interesting alternatives to improve road safety.

Unfortunately, this potential benefit - and well proven effectiveness - of road markings is not sufficiently exploited by the relevant decision makers. This is well demonstrated by the fact that, at present, most national regulations or technical specifications on this subject lay down minimum values for the parameters which define their essential characteristics (night and day time visibility and skid resistance) without always taking into account the real visual demands of drivers.

Therefore, there is an urgent need to establish an up-to-date scientific method with which, on the basis of drivers' visual needs, to determine the optimum pavement marking design in order to ensure that it is visible, by day and by night, in all weather conditions. Only after having validated uniform criteria for the appropriate design of the road markings, will drivers be able to enjoy a harmonised quality of road markings capable of positively contributing to improve their road safety level in Europe.

This level of safety throughout the European road network is a right for drivers as well as an obligation for the European Union authorities as stated in Single Market legislation in 1987 (Article 100 a) and the Treaty of Maastricht in 1993 (Article 75).

Chapter 2. General description of the Action

The final purpose of COST 331 is to establish an up-to-date scientific method with which, on the basis of drivers' visual needs, to determine the optimum pavement marking design in order to ensure that markings are visible, by day and by night, in all weather conditions.

At present, most research in this area, both national and international, concentrates on:

- Development of new marking products which meet the above mentioned requirements for as long as possible (maximum functional life), and

- Design of new technologies for the manufacture of high-performance equipment for assessing those requirements.

Scientifically validated uniform criterion are therfore needed for the appropriate design of road markings in order to provide the following "benefits" to different users:

For drivers:

- Optimisation of the cognitive load;
- Achievement of visual guidance by day and night in all weather conditions

For road authorities:

- Availability of a scientifically validated methodology for designing road markings;
- Maximisation of the cost-effectiveness of road markings.

This work has been confined to longitudinal road markings (of two types: conventional and those designed to maintain night time visibility in adverse weather conditions) including directional arrows. The colour of road markings is not considered itself as a variable to be included in the different experimental phases.

The application field of the road markings covered by the Action is restricted to interurban roads (motorways, dual carriageways and single carriageways). Therefore, pavement markings applied in urban areas are outside the scope of this research.

For its execution, the research programme was subdivided into **four main sections**, linked among themselves, dealing with the necessary tasks identified in the preparation of COST 331.

Section 1 (described in Chapter 4) deals with the **"state of the art"**, in the area falling within the Action's scope. To that purpose, an appropriate questionnaire, to be filled in by means of subsequent interviews with relevant decision-makers in Europe, has been prepared and circulated. This section includes a summary of the answers provided as well as the more remarkable resulting conclusions.

Section 2 (covered by Chapters 5 and 6, respectively) describes the background to the objective of **"designing a mathematical model for the computation of visibility distances to road markings"** and the identification of **"driver's visual needs"**. On the one hand, road markings supply certain visibility distances to drivers depending on the road markings themselves as well as on the conditions and, on the other hand, the supplied visibility distances may or may not be sufficient in view of the driver's demand related to the intended purposes of the road markings.

The first subtask relates to *basic visual performance data* and provides a mathematical model for the computation of visibility distances supplied by road markings. The model includes the geometrical lay-out and the reflection properties of road markings, and conditions of illumination and observation.

The second subtask clarifies *drivers' demands of visibility distances*. It is focused on visual guidance supplied by existing pavement markings. The demands are expressed as preview times from which visibility distances can be computed according to driving speed.

Section 3 (described in Chapter 7) deals with field experiments intended to **"evaluate the impact on road safety of road markings"** by monitoring the behaviour of different (selected) drivers through experimental road sections properly designed and marked.

It was not practicable to evaluate the benefits of road markings by monitoring accidents. The influences of markings on road safety were therefore inferred from behavioural changes. These behavioural effects were measured on two levels:

- adaptation of individual drivers to road markings and
- effects of road markings on the speed of traffic flow.

Two primary groups of variable used to describe safety effects on driver behaviour were speed related factors and the lateral stability of a vehicle in relation to the centre/edge line. Problems associated with the lateral position of a vehicle and its relation to safety are treated in this section. It is assumed that the higher the speed level and variability, and the greater any sudden shifts in the lateral position of a vehicle, the less safe the driving behaviour.

Section 4 (described in Chapter 8) provides **"a guide for the use of road marking elements on roads of different classes"**. The contrast, the connection between width and reflection and other geometrical measures are stated for different types of longitudinal lines used in several countries in Europe, on motorways, dual carriageway and single carriageway roads.

The guide shows how to combine those elements, in order to provide needed visibility, and offers user-friendly computer support with the methodology to calculate the visibility distance provided by road markings.

In figure 2.1, the different tasks and sub-tasks developed in COST 331 as well as the execution time programmed for each of them have been tabled.

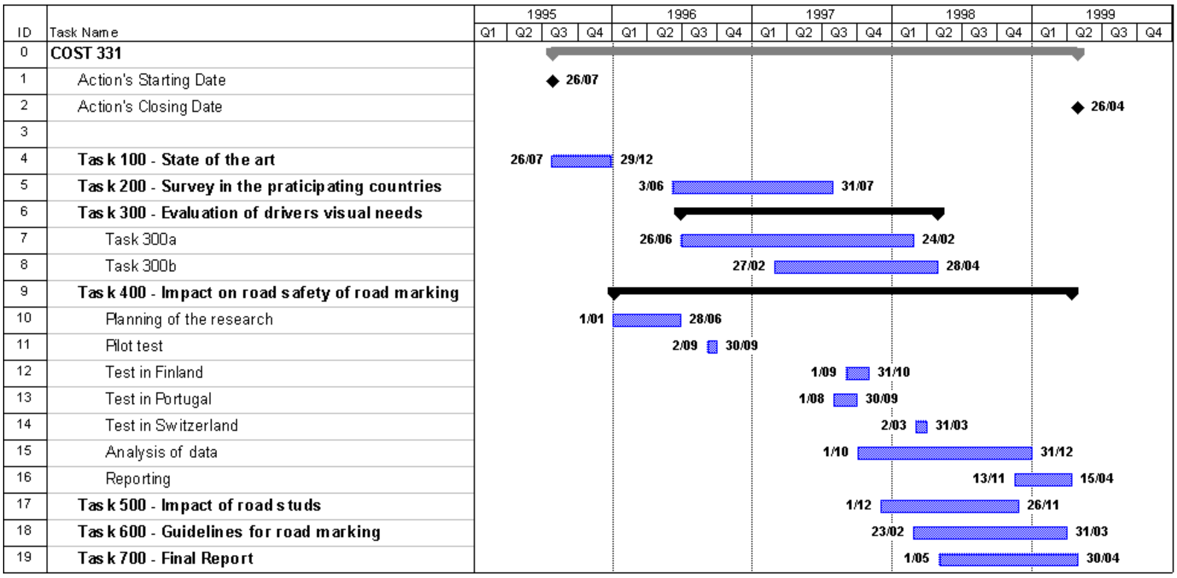


Figure 2.1 - COST 331 GANTT chart

The members of COST 331 were from 15 COST countries: Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Italy, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland and the United Kingdom.

Each participating country signed a Memorandum of Understanding whereby their Governments agreed to co-ordinate their research effort toward meeting the aims of COST 331.

The execution of COST 331, while supported by the European Commission, has been directed by a Management Committee drawn from the Membership - the latter comprised government representatives, academics and other experts in the field.

The work undertaken by COST 331 is based upon the fruitful contribution of the 15 signatory countries mentioned above and shown on the map in figure 2.2. In addition, Ireland, the Netherlands and Norway have also contributed to this work although they did not sign the Memorandum of Understanding.

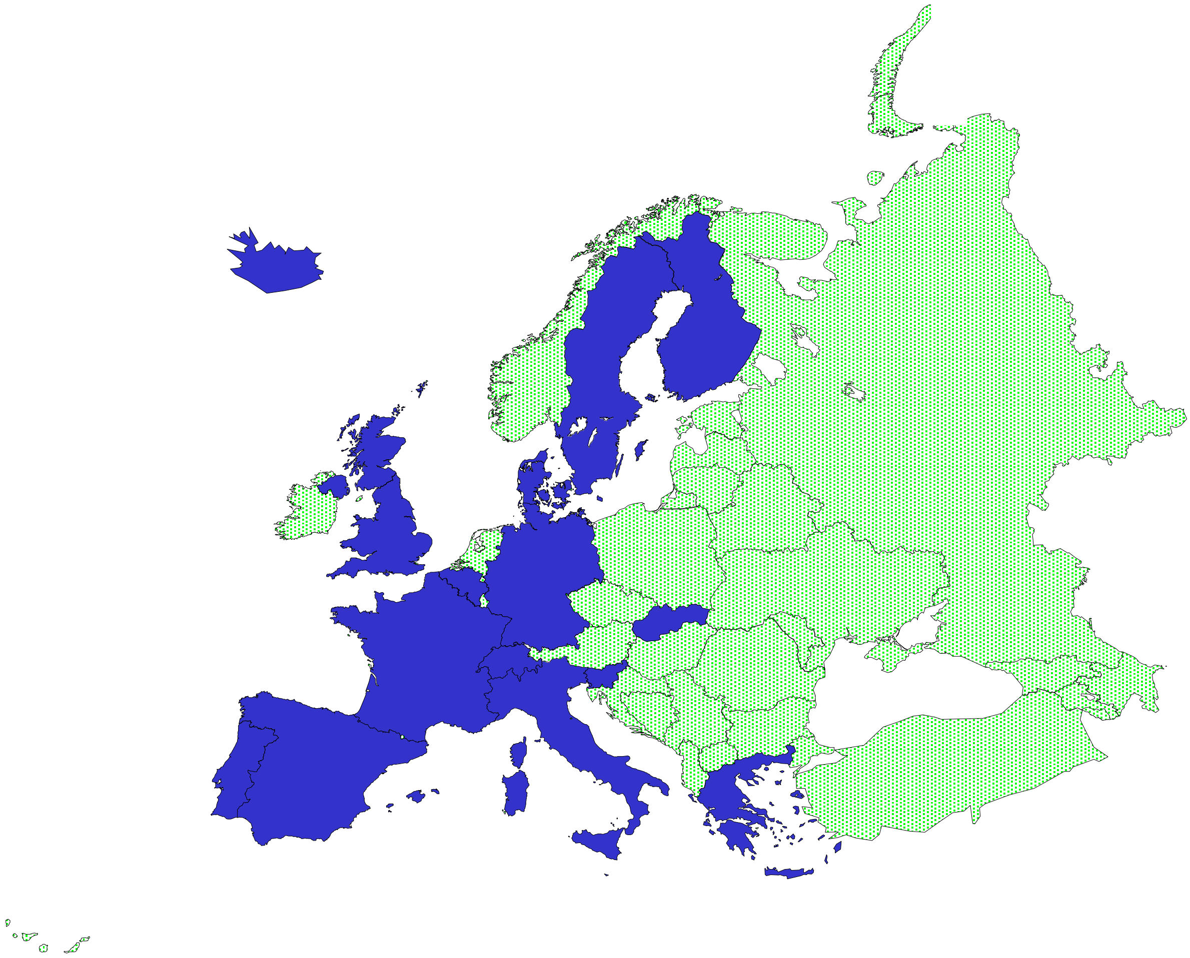


Figure 2.2 - Participating countries

Chapter 3. Executive summary

At present, most national technical specifications for road markings lay down minimum performance levels for the parameters defining their essential characteristics (namely: *night time and day time visibility and skid resistance*) without having considered sufficiently the relationship between what the driver needs, for appropriate guidance, and what the road marking is able to provide (in terms of visual information).

Furthermore, research in this area, both national and international, concentrates on:

- developing new marking products which meet the above mentioned performance levels for as long as possible (maximum "durability", understood as *"retained performance"*) and
- designing new technologies for the manufacture of high-performance equipment for assessing those requirements.

Road markings are, in fact, "traffic signals" with a decisive impact on driver's safety mainly because they are non-verbal (their message being expressed through design and colour) and, in consequence, readily understood by drivers and because, in poor lighting or bad weather conditions (when the information drivers get from the environment is limited to the areas illuminated by the headlamps of the vehicle), they are one of the most relevant elements to guide drivers safely along the road.

It is therefore indispensable to have available a proven scientific basis for answering the most relevant questions concerning the design and use of road markings, such as:

- what is the visibility distance provided by a certain type, and quality, of road marking?;
- what is the visual demand of drivers, as far as road markings is concerned?....

The results of COST 331, by establishing an up-to-date scientific method with which to determine the optimum road marking design (in order to ensure that markings are visible by day and by night, in all weather conditions), provide that necessary basis allowing research, industry and road traffic engineers to improve - where necessary - the current value of road markings for drivers.

The execution of the research programme, designed and approved by the COST 331 Management Committee, included:

1. A complete review of the state of the art by means of a literature survey and a questionnaire answered by 15 European countries.
2. An investigation of the visibility distance of road markings, in a driving experiment involving a number of test persons and variable conditions (concerning road marking pattern and reflectivity, and headlamp intensity).
3. An investigation of the driver need for visibility distance, carried out in a driving simulator, involving a number of test persons and variable conditions concerning driving speed, visibility distance and road curvature.
4. Monitoring driver behaviour in real traffic conditions throughout different road sections in Finland, Portugal and Switzerland (built up with different designs and quality of road markings), by using an unobtrusive instrumented car and involving a statistically selected number of test persons.

From the analysis of the results of the questionnaire, it can be stated that all countries do have national regulations or technical recommendations which specify geometry, design and colour of road markings. However, and probably resulting from the lack of scientific background, the design of road markings vary from country to country. In some countries, additionally, the use of a type of road marking intended to improve night time visibility under wetness or rain is also prescribed.

The lack of a proper scientific background referred to above is also reflected in the criteria for the use of colours. While there seems to be a general consensus on the colour of the permanent road markings (for this purpose, most countries in Europe use **white**), agreement on a standard colour for temporary road markings still has to come (although most countries use **yellow**, **white** and **orange** are currently used as well).

The investigations of the visibility distance of road markings and of the driver need for visibility led to the development of a computer programme which allows the calculation for a given type of vehicle, driver, environment, headlamp and quality and design of the road marking, of the visibility distance and preview time of longitudinal road markings. This computer programme is useful for research and education and as a tool for deriving a national policy on road markings.

The previously mentioned researches, when combined with the analysis of driver behaviour (monitored in the three cited field experiments) and the existing literature on this topic, also suggest that road markings should be able to provide a preview time of 3 to 5 seconds to achieve comfort as well as safety[1].

Finally, the results of COST 331 were able to demonstrate the influence of road markings on the behaviour of drivers who adapt their driving attitude (basically, speed) to the information (i.e. visibility distance) deriving from the road markings. However, more research needs to be done before any direct link can be established between such changes in driving behaviour and road safety. This is all very well, but it is not technically possible to provide markings giving a night time preview time of 5 seconds in all conditions; this could require visibility distances exceeding 150 metres.

The conclusions show that there is a need to establish a national policy (taking account of driver age, headlamp intensity and glare from opposing traffic and climate) for road marking design, due to their influence on road safety. To do that, the scientific basis - and evidence - provided in COST 331 can fruitfully be used. Nevertheless, COST 331 does not provide answers to all the questions which may be asked in connection with road markings - further research is needed to achieve that - but has taken a big step forward in establishing better knowledge of the driver's visual needs and the capability of road markings to provide information. COST 331, in this sense, provides an outstanding scientific background for future research in this field.

[1] Preview time is defined as the number of seconds taken to drive a distance equal to the visibility distance. In chapter 6, it is concluded that 1,8 seconds should be considered as the minimum preview time needed just for safe driving. Later on, the results of the field experiments (chapter 7) suggest that a mean preview time of 2,2 seconds is even too short for driving confort.

Chapter 4. State of the art

4.1 Introduction

Today's experience leads to a quite simple conclusion: road markings are signals with a very simple message (when retroreflecting road studs are placed on the road, even having no particular coded message in the legal sense, they clearly mark - for instance - the centre of the carriageway). Their influence on traffic safety is duly noted in the OECD report (1975) "Road marking and delineation" in which it is stated:

"A clear and precise system of horizontal signing in the form of road markings together with lateral delineators (posts) serves a special purpose by facilitating driver guidance, thus improving traffic flow and contributing to driving comfort and safety."

Surprisingly, this indispensable road equipment, in spite of the fact that it serves the same intended use (upgrading road safety) regardless of the country, is subjected to different regulations and technical specifications in Europe. This should not be a problem as long as the same level of road safety is achieved. However, experience suggests and a literature research confirms that little scientific research had been carried out by road authorities and authorized third parties to design appropriate road marking systems (definition of performance, colour, shape, dimensions, application criteria, etc.) ensuring a minimum traffic safety level. In consequence, establishing the "state of the art" in the field of road markings is a necessary first step in the preparation of strategies to achieve convergence in the current differences in road safety in different European countries.

This phase of the work, therefore, deals with the "state of the art", in the area falling within the Action's scope. To that purpose, an appropriate questionnaire, to be filled in by means of interviews with relevant decision makers in Europe, was prepared and circulated (*for the text of the 'questionnaire' refer to the CD-ROM*).

This questionnaire is divided into three parts:

- Part 1: Road markings.
- Part 2: Retroreflective road studs.
- Part 3: Additional information.

The participant countries (14) completing the questionnaire were: Belgium (B), Switzerland (CH), Germany (D), Denmark (DK), Spain (E), France (F), Finland (FIN), Greece (G), Iceland (ICE), Ireland (IRL) the Netherlands (NL), Sweden (S), Slovenia (SLO) and the United Kingdom (UK).

Through the analysis of the answers provided, information about WHY road markings and retroreflective road studs (RRS) are used, WHICH criteria are used as background for current regulations and technical specifications, WHICH criteria are presently used for determining maintenance and relevant BIBLIOGRAPHY can be found (*for the complete report on the answers collated during the survey, refer to the CD-ROM*).

4.2 Results of the Questionnaire

As has been described in the previous section, the “state of the art” was identified by means of interviews with relevant decision makers in Europe. The analysis of the answers resulting from the survey constitute real background information enabling valuable conclusions to be reached about the road marking systems used in Europe.

To make that analysis more comprehensive for non-expert readers, the results are presented in this section as appropriate answers to the most relevant questions included in each section of the questionnaire.

Special consideration should be paid to the use of retroreflective road studs. For these devices, in addition to the treatment of the information gathered from the survey, an analysis of the existing literature in English, French and German has been made (*for the complete report on this analysis refer to the CD-ROM*). Unfortunately, the usable information is rather limited and not closely linked to the main goal of this part of COST 331. However it is clear that *the use of retroreflective road studs is not widespread in Europe and their use is inconsistent*. This is rather dismissive. Studs have considerable visibility advantages over markings, in wet or foggy weather.

Part 1: Road Markings

Question 1 - Everybody is used to see pavement markings on roads but has anyone wondered whether their application is compulsory by legislation?

Within the consulted countries, in only three of them: FIN, UK and IRL the application of road markings is not compulsory. However, there are criteria for their use.

It should be noted that in the 11 countries where the application of road markings is compulsory by legislation, it is almost impossible to extend the use of road markings (e.g. to use centre lines on roads where only edge lines are prescribed).

Question 2 - What criteria are used for recommending the application of road markings?

Regardless of the fact of having or not having regulations for road markings, *the road width in combination with the Average Daily Traffic (ADT) and accident frequency* is the most commonly used criteria.

Surprisingly, in spite of the fact that road markings are intended for the same purpose (road safety), their design varies from country to country. That might be due to the fact that *none of the countries appears to have carried out scientific research to support their technical specifications or regulations.*

Therefore:

- **On motorways:** Only IRL uses broken lines for left or right edge lines. E and F use broken lines for right edge lines only (all other countries use continuous lines). The width of edge lines varies from 0.15m to 0.30 m, while for lane markings, the width varies from 0.10m to 0.20m and length from 2.0m to 6.0m.
- **On interurban dual carriageway roads:** Only IRL and S use broken lines for left and right edge lines. E and F use them for right edge lines only (all other countries use continuous lines). The width of edge lines varies from 0.10m to 0.30m, while

for lane markings, the width varies from 0.10m to 0.20 and length from 2.0m to 6.0m.

- **On interurban single carriageway roads:** Only F, ICE, IRL and S use broken lines as edge lines. Their width varies from 0.10m to 0.30m. The width of centre lines varies from 0.10m to 0.15m and the length from 1.0m to6.0m.

Finally, it should be noted that in most cases international agreements (e.g. Agreement of the Economic Commission of the UN, Vienna, 1968 and the European Protocol on Road Markings, Geneva, 1971) as well as national regulations of other countries (generally speaking, adapted - totally or partially - to national traffic and road conditions) have been the basis used as background for national specifications or regulations on road markings.

Question 3 - Is there any consensus about the colour to be used in pavement markings?

For permanent road markings, the consensus throughout Europe seems to be evident: WHITE. In IRL and SLO only edge lines are yellow. In FIN, both white and yellow are used for longitudinal lines, chevrons and hatch markings.

The situation is not so clear for temporary road markings used at road works where although most countries use YELLOW, FIN, ICE, SLO and the UK use white and in G and IRL *both colours* (white and yellow) are used. In CH and S only *orange* is used. In B only *orange retroreflecting road studs* are used, while in the UK *yellow* temporary road studs are used at road works.

Question 4 - The use of type 2 road markings (those designed to improve night time visibility under difficult weather and traffic conditions) is becoming increasingly widespread. But is their use regulated in Europe?

Some countries do not use type 2 road markings (i.e. those capable of maintaining night time visibility in adverse weather conditions): FIN, G, ICE, IRL and SLO. In spite of the fact that in other countries their application is recommended in some cases (B, CH, E and NL), only D, DK, F, S and UK set national regulations or technical recommendations prescribing the use of these markings:

Profiled is the most common design of type 2 road markings. Systems based on large glass beads are also used in B, CH, D, F and UK. The reason for this is that noise (“wake up markings”) is increasingly considered by decision makers to be a characteristic of type 2 road markings as important as improved night time visibility. *It seems to be obvious that a type 2 road marking should include these two essential characteristics: improved night time visibility and mechanical - acoustic effect.* Finally, the application field of type 2 road markings is restricted to *longitudinal lines (mostly on edge lines) and on roads outside urban areas*. However, type 2 road markings are also used on hatch markings in D and F, on motorways. In addition, F uses those markings for chevrons and directional arrows as well as on dual and single carriageway roads.

Therefore it can be stated in this field also, that there is a lack of investigation. Only D, DK, S, F and the UK have carried out some research on the use of type 2 road markings.

Question 5 - The most important way of improving road safety by means of road markings is by implementing appropriate regulations or technical specifications, but:

Question 5.1 - Do road authorities consider that those regulations satisfactorily meet current traffic needs, in their countries?

For different reasons, only 5 countries (DK, E, FIN, G and SLO) recognise that their current standards do not meet present traffic needs. However, CH, DK, F, FIN, G, S and SLO are presently considering improvements or changes in national regulations.

Question 5.2 - Are the environmental protection and the traffic disturbance (application speed, drying time, etc.) characteristics considered essential by road authorities?

In general, it can be stated **YES**. This is reflected in the national regulations or technical specifications of several countries. *The absence of aromatic or organic solvents and lead in combination with fast drying materials* are the most common requirements to achieve environmental and traffic protection during and after the application of road marking products.

Question 5.3 - Specifying appropriate guarantees for road marking performance (day and night time visibility and skid resistance), is the last requirement to be prescribed in technical specification and regulations. ***Is that the situation in Europe today?***

NO. The vast majority of countries prescribe the use of certified products along with a minimum guarantee for the road markings. Those guarantees vary considerably from country to country: e.g. in IRL and S, 2 years regardless of the type of product. In D, 1 year for paints, 2 years for cold plastics and thermoplastics and 4 years for inlay thermoplastics are required.

Considering the minimum and maximum periods currently specified, it can be stated that the guarantees in Europe vary between 1 to 4 years.

Question 6 - Special attention should be paid to road marking MAINTENANCE.

Question 6.1 - What sort of criteria determine road marking maintenance in Europe?

Budget and minimum road marking performance are the most important criteria.

Question 6.2 - Are European road authorities happy with their criteria for determining maintenance programmes?

Although budget constrictions, together with limited ability to monitor road marking quality, are strong influences on maintenance expenditure, road authorities would like to improve the present situation. Within the possible alternatives, it seems that they would like to be able to plan road marking maintenance programmes to restore performance levels *whenever these decline to the minimum values specified*.

Part 2: Retroreflective Road Studs

In general, the use of retroreflecting road studs (RRS) is not widespread enough to reach reliable conclusions from the answers of the participating countries. However, these provisional results offer sufficient information to understand a bit better the contribution of retroreflective road studs to improving road safety.

In general, retroreflective road studs are considered as a horizontal road marking which presents some particular advantages for traffic safety in respect of visibility at night or in adverse weather conditions (fog, rain, etc.). The general consensus is that the use of RRS in high hazardous locations does enhance delineation and improves the overall safety of those road sections (that is the main reason why they are used to supplement conventional road markings or even to replace them).

On the other hand, and based on the available literature, it is difficult to assess quantitatively the effectiveness of RRS. Studies carried out on this topic conclude that **the use of RRS provides a valuable guidance system**, but none of them quantify that added value.

Question 1 - Is the application of RRS compulsory by legislation?

Only few countries have legislated the use of RRS: E, the NL, S and the UK.

The use of RRS varies from country to country not only within the same type of application (permanent or temporary) but in their field of application (e.g. in G, RRS are used exclusively in construction work zones meanwhile, in Sweden, sometimes they are used in these zones and very seldom for permanent applications).

Question 2 - What criteria are used for recommending the application of RRS?

In general *there is no single criterion in Europe to determine the application of RRS*. The reason may partly be the lack of consistency in the use of these devices. Improved visual performance in adverse weather conditions seems to be one of the most common justifications for their use.

It should be pointed out that all countries which use RRS for permanent applications have national regulations - or technical recommendations - to specify their installation criteria. The exception is SLO where installation criteria are fixed tender by tender. However, in spite of finding differences in the installation criteria among the countries using RRS in permanent applications, it can be stated that their intended use is similar: **to substitute for or to supplement longitudinal lines**.

Question 3 - Appropriate regulations and technical specifications for retroreflective road studs are indispensable to achieve the efficiency of these devices, but:

Question 3.1 - Present regulations and technical specifications do not meet current traffic needs:

Only two countries (IRL and the UK), among the users of RRS, consider that their applicable regulations do not need to be improved.

The most widespread opinion about how to improve regulations and technical specifications of RRS is by means of *specifying their application areas* (EN 1463-1 shall be used as initial performance standard only).

Question 3.2 - There are no installation criteria specified in relationship with environmental protection and traffic disturbance:

Even being used for permanent applications, only the UK has technical requirements on these topics:

- avoiding hazardous materials;
- high application speed and long durability (functional life)

Question 3.3 - There are no single criteria to specify guarantees:

In some countries (e.g. G and E), it is enough to get applied RRS manufactured according to initial performance specifications. Others (e.g. DK and the UK), in addition specify functional lives: from 1 to 4 years, in permanent applications and just 3 months in temporary.

Question 3.4 - Budget and minimum performance are the most important criteria to determine RRS maintenance, however:

Road authorities would like to improve the present situation. Within the possible alternatives, it seems that they would like to be able to plan road studs maintenance programmes to restore performance levels *whenever these decline to the minimum values specified*.

Part 3: Additional Information

With regard to the road safety benefits of using road studs or special types (profiled road markings, etc.) of road markings, only DK and E know of related research that could help road authorities in making appropriate decisions.

With regard to the use of ***"masking materials"*** (used to temporarily mask permanent road markings in construction work areas), only DK, NL and the UK have national regulations or technical recommendations on the visual performance of those products.

4.3 Conclusions

- Regardless of the fact of having, or not having, regulations, *the road width in combination with the Average Daily Traffic (ADT) and accident frequency* are the usual criteria in recommending the application of road markings.

- Surprisingly, in spite of the fact that road markings are intended for the same purpose (road safety), their design varies widely from country to country. That might be due to the fact that *none of the countries appears to have carried out scientific research to support technical specifications or regulations*.

- For permanent road markings, the consensus about the "colour" throughout Europe seems to be evident: most countries use only WHITE. In IRL and SLO edge lines can be yellow. In FIN, white and yellow can be used for longitudinal lines, chevrons and hatch markings.

- However, the situation is not so clear for temporary road markings. Although most countries use YELLOW, FIN, ICE, UK and SLO use white while in G and IRL *both colours* (white and yellow) are used in CH and S only *orange* is still used. In B *orange retroreflecting road studs* are used.

- There are countries that do not use type 2 road markings (those designed to maintain night time visibility in adverse weather conditions): FIN, G, ICE, IRL and SLO. In spite of the fact that in other countries their application is recommended in some cases (B, CH, E and NL), only D, DK, F, S, and UK have national regulations, or technical recommendations, prescribing the use of these markings (restricted to longitudinal lines and on road sections outside the urban areas). **Profiled** is the most common design of that type of road markings.

- For different reasons, only 5 countries (DK, E, FIN, G and SLO) officially recognise that their current standards do not meet present traffic needs. However, CH, DK, F, FIN, G, S and SLO are presently considering improvements or changes to national regulations.

- Although budget constrictions, together with limited ability to monitor road marking quality, are strong influences on maintenance expenditure, road authorities would like to improve the present situation. Within the possible alternatives, it seems that they would like to be able to plan road marking maintenance programmes to restore performance levels *whenever these decline to the minimum values specified*.

- Based upon the limited amount of available literature, it is possible to assert that retroreflective road studs (RRS) - used for substituting or supplementing conventional road markings (especially longitudinal lines) - are an effective means of improving guidance to drivers particularly in adverse weather conditions. However, the current lack of research in this field makes it impossible to state any figure concerning the "effectiveness" of RRS in road safety.

Chapter 5. Visibility of Road Markings

5.1 Introduction

This chapter describes the methodology used to develop a model for the calculation of the visual information (called **"visibility level" – VL**) provided by road markings

The preparation of a visibility model, capable of calculating the visibility distance provided by road markings under different traffic conditions (cars, age of driver, weather,...), is required to deal with, and to calculate, the **supply of visibility**.

The starting point was to use a general model for the visibility of targets on backgrounds. The model used refers to a laboratory situation and cannot readily be applied for the complex road situation. A trial error and procedure may be used to determine the visibility distance, defined as the *distance where the visibility level has a selected value*. The model developed in COST 331 may therefore be considered a replacement for the methodology given, for the same purpose, in CIE report Nº 73 which has a smaller range of applicability and lack of support from driving experiments.

5.2 Calculation procedure

The calculation procedure, for the "visibility level" (VL) of a road marking**,** involves the following steps:

a) Calculate the equivalent target size of the road marking.
b) Calculate the luminances of the road marking and the road surface.
c) Calculate the visibility level (VL) according to Equation 1.
d) Evaluate the calculated visibility level. A minimum level of 10 for practical driving situations is recommended.

If the visibility distance is to be computed, a further step is added:

e) If the calculated visibility level is higher/lower than the selected value, then increase/decrease the distance to the road marking and repeat steps a) to d), otherwise accept this distance as the visibility distance.

The equivalent target size of a road marking, to be computed in step a), is the size of a circular target of the same solid angle as obtained by integration over the surface of the road marking.

The basic equation used for the VL of a target was (equation 1):

$$\mathbf{VL = \Delta L \times \alpha^2/(A + B \times \alpha)^2} \qquad \text{(}\mathit{Equation\ 1}\text{)}$$

where

α is the target size in minutes of arc.
ΔL is the luminance difference in (cd/m^2).
A and B are functions of the background luminance (L_b) in (cd/m^2).
VL is the visibility level.

When the luminance is uniform, for example for a transverse road marking, the solid angle is the apparent area of the road marking divided by the distance squared. Therefore, a road marking of area A which is seen at an angle of view v will have an apparent area:

$$\mathbf{A' = A \times cosv} \qquad \textit{(Equation 2)}$$

with a solid angle of ($\frac{A'}{D^2}$), being D the distance to the road marking.

When the luminance varies, for example along a longitudinal road marking, a weight of L/L_o is applied to each element of the surface area before integrating the solid angle. L is the luminance at the location of the element and L_o is the luminance at the front end of the road marking.

Section 5.3 gives more precise instructions on how to compute the equivalent target size.

Luminance, to be computed in step b), is found as the product of the illuminance produced by a light source and a luminance coefficient representing the type of illumination, the geometrical situation and the surface. When more than one light source is present, luminances produced by each are added to provide the total luminance.

When the luminance is uniform, only two luminance values need to be calculated, one for the road marking and one for the road surface.

When the luminance varies, the luminance of the road marking at the front end L_o is selected to represent the road marking. The luminance of the road surface next to this location is selected to represent the road surface (background luminance L_b). Luminances of the road marking at other locations are needed for the calculation of the equivalent target size, see the discussion above.

Section 5.4 gives more precise instructions on how to compute luminances for headlamp illumination and for daylight/road lighting.

Prior to the calculation in step c), substitutions may be carried out in order to take glare and/or age of the driver into consideration according to sections A.3 and A.4, of annex A, respectively.

As a practical expression of the model, a computer programme using the model has been developed and included in the CD-ROM attached to this final report. The programme may be useful during revision of national regulations and technical specifications.

The mentioned programme operates in a single page which has enough room for the following input:

- driver, vehicle and glare;
- road marking geometry and location;
- road geometry;
- headlamp illumination and coefficients of retroreflected luminance (R_L);
- daylight/road lighting and luminance coefficient in diffuse illumination (Q_d).

5.3 Calculation of target size

5.3.1 Equivalent target size of a road marking

The basic equation (Equation 1) uses parameters defined for a simple laboratory situation, in which a circular target of uniform luminance is presented on a background also of uniform luminance. The target size is measured by the angular diameter in minutes of arc.

In this case, a road marking forms the target, while the road surface forms the background. However, the road situation is more complex than the laboratory situation. Firstly, a road marking is generally not seen as a circular target and, secondly, the luminances of both the road marking and the road surface may be non-uniform. Therefore, a translation from the road situation to the laboratory situation is needed.

- The translation uses the same substitution of the road marking by a circular target, as used in annex B for the purpose of analyzing experimental visibility distances. The validity of the translation is discussed in section 5.6, while the calculation of luminances is accounted for in section 5.4. The substitution leads to an equivalent target size which can be defined as the *"size of a circular target of the same solid angle as obtained by luminance weighted integration over the surface of the road marking"*.

Accordingly, the target size α measured in minutes of arc, of a road marking is obtained by:

$$\boldsymbol{\alpha = 3879\sqrt{\omega}} \qquad \textit{(Equation 3)}$$

where ω is the solid angle of the road marking obtained by luminance weighted integration and measured in steradians (sr)

The integration over the surface of the road marking is given by:

$$\boldsymbol{\omega = \int L d\omega / L_o} \qquad \textit{(Equation 4)}$$

where **dω** is the solid angle of a small element.
L is the luminance at the location of the element.
$\mathbf{L_o}$ is the selected target luminance.
and ∫ means integration over the surface.

The term dω is given by $\mathbf{d\omega = cosv \times dA/D^2}$, where dA is the area of a small element, cosv is the cosine to the angle of view to the element and D is the distance. The angle of view v is measured from the direction of view to the normal of the road surface.

5.3.2 Target size of transverse road markings

By transverse road markings is meant localised road markings of limited area such as arrows, give-way markings and stop-lines.

The luminance of such road markings may be assumed to be constant over the surface area. When viewed from a distance much larger than the extent of the road marking, the angle of view v is also roughly constant. Equation 4 then reduces to:

$$\boldsymbol{\omega = \cos v \times A/D^2} \qquad \textit{(Equation 5)}$$

where **A** is the area of the road marking.
D is the distance to the road marking.
and **v** is the angle of view to the road marking.

When the road is plane, and the observer is at a height H_o and the distance to the road marking D is much larger than H_o, the term cosv may be replaced by H_o/D. Therefore the expression for ω becomes :

$$\boldsymbol{\omega = H_o \times A/D^3} \qquad \textit{(Equation 6)}$$

5.3.3 Target size of longitudinal road markings

By longitudinal road markings is meant edge lines, centre lines, lane dividing lines and other long markings such as long fields of hatch markings.

The situation is that a longitudinal marking starts, or changes geometry, at a distance D in front of the driver and from there on continues for some distance which is not small compared to D.

Because of the length of these markings, the angle of view v is not constant along the marking. Further, the luminance might change depending on the type of illumination. The integration of equation 4 has to be carried out for the individual cases.

For continuous lines, the integration leads to a simple result in some cases. For instance :

- A continuous line on a plane road surface has a width W and a constant luminance L_o.When observed from a height H_o, equation 4 gives the result $\boldsymbol{\omega = 0{,}5 \times H_o \times W/D^2}$. This is typical of daylight illumination.

- A continuous line on a plane road surface has a width W and a luminance given by L_o/D^2. When observed from a height Ho, equation 4 gives the result $\boldsymbol{\omega = 0{,}25 \times H_o \times W/D^2}$. This is typical of vehicle headlamp illumination.

For broken lines, the result of the integration depends in principle not only on the total road area covered by the road markings, but also the details of the pattern. However, annex B demonstrates that a broken line can be handled as a continuous line with a reduced width given as the area covered per unit length. Such a simplification should be permissible also for hatch fields and similar.

5.4 Calculation of luminance

5.4.1 General

The luminance of a road marking or a road surface illuminated by a single light source is calculated as the product of the illuminance produced by the light source and a luminance coefficient.

When more than one light source is present, the contribution to the luminance from each of the light sources is calculated separately and added to provide the total luminance.

The value of the luminance coefficient is characteristic of the road marking or the road surface, and depends on the illumination and observation geometry.

Different definitions apply for headlamp illumination, and for road lighting and daylight.

As explained in section 5.3.1, the basic equation (Equation 1) is derived for a simple laboratory situation, in which a target of uniform luminance is presented on a background also of uniform luminance.

When the illumination is non-uniform over the surface of a road marking, the luminance will also be non-uniform. For such cases, a transposition from the road situation to the laboratory situation is needed. For that transposition (annex B), in order to analyze the experimental visibility distances, the luminance of the road marking at the point on the road marking closest to the observer is used for the target luminance while for the background luminance, the luminance of the road surface at a point next to the above mentioned point is used.

The validity of the above-mentioned transposition is discussed in section 5.6.

5.4.2 Headlamp illumination

The luminance L measured in $cd \cdot m^{-2}$ at some point of a road marking or a road surface in headlamp illumination is calculated by:

$$\mathbf{L = \Sigma R_L \times E_\perp} \qquad \textit{(Equation 7)}$$

where **R_L** is the coefficient of retroreflected luminance measured in $cd \cdot m^{-2} \cdot lx^{-1}$.
$E_\perp$ is the illuminance by a headlamp at the point on a plane perpendicular to the direction of illumination measured in lx.
and **Σ** means summation for two or more headlamps.

The coefficient of retroreflected luminance R_L is defined in the European standard EN 1436, "Road markings materials – Road marking performance for road users, 1997", which also introduces a standard measuring geometry and classes of minimum R_L values.

The unit of R_L is in principle $cd \cdot m^{-2} \cdot lx^{-1}$ (ratio between luminance measured in $cd \cdot m^{-2}$ and illuminance measured in lx), but in practice to obtain convenient values, the one thousand times smaller unit of $mcd \cdot m^{-2} \cdot lx^{-1}$ is used.

The standard measuring geometry is defined by the values of the observation angle α and the illumination angle ε of 2,29° and 1,24° respectively. These angles are measured from the horizontal to the directions of observation and illumination respectively (these two directions are in the same vertical plane). This measuring geometry represents the situation obtained for a driver looking 30 m ahead with his eyes at a height of 1,2 m and a headlamp just below the eyes at a height of 0,65 m.

For the dry condition, EN 1436 provides classes of minimum R_L values of 100, 200 and 300 $mcd \cdot m^{-2} \cdot lx^{-1}$ for white road markings and classes of minimum R_L values of 80, 150 and 200 $mcd \cdot m^{-2} \cdot lx^{-1}$ for yellow road markings. Additionally, EN 1436 defines classes of no requirement for cases where retroreflectivity is not relevant.

Road surfaces in the dry condition have R_L values in the range from 5 to 30 $mcd \cdot m^{-2} \cdot lx^{-1}$. The lower end of the range applies for asphaltic road surfaces with dark stone aggregates, while the upper end of the range applies for asphaltic road surfaces with more light stone aggregates and cement concrete surfaces.

For most road markings in conditions during rain or wetness, R_L drops to very low values. Road markings with a strong surface texture, such as profiled road markings, or using other means achieve the same purpose, maintain some retroreflectivity during rain or wetness. For such road markings, EN 1436 provides classes of minimum R_L values of 25, 35 and 50 $mcd \cdot m^{-2} \cdot lx^{-1}$.

For road surfaces in conditions during rain or wetness, the R_L drops to low values of typically 0 to 10 $mcd \cdot m^{-2} \cdot lx^{-1}$.

The variation of the R_L value with the measuring geometries have been sufficiently analysed and enough data exist in the literature. For the application of the model it is recommended that the standard geometry (as specified in EN 1436) is used.

The illuminance $E_\perp$ at a point, created by a headlamp is defined as:

$$\mathbf{E_\perp = I/D^2} \qquad \textit{(Equation 8)}$$

Where **I** is the luminous intensity of the headlamp in the direction towards the point measured in cd.
and **D** is the distance from the headlamp to the point measured in m.

The luminous intensity depends on the headlamp, and on the direction. For detailed calculations, a table of luminous intensities must be available for the headlamp in question covering the relevant directions. In directions within the beam of a classical headlamp, luminous intensities are typically about 10.000 cd. For some modern types of headlamps, luminous intensities may be considerably higher. For example, a vehicle with two headlamps with luminous intensities of 10.000 cd each in the high beam position, for the relevant directions, at a distance of 100 m, the road surface luminance is equal to 0,03 $cd.m^{-2}$ (considering a R_L value for the road surface of 15 $mcd \cdot m^{-2} \cdot lx^{-1}$) using equations 7 and 8.

In general, it can be stated that background luminances in headlamp illumination are generally small, the relevant range to be considered being 0,001 to 0,1 $cd \cdot m^{-2}$.

With background luminances in this range, a high contrast is required for the visibility of relatively small targets. This is the basis for the use of micro-beads to enhance the retroreflectivity of road markings and thereby the contrast with the road surface.

The need for high contrast brings visibility conditions into the domain of **Ricco's law**, or at least partly into this domain. In this domain, the visibility level is in proportion to the term $\Delta L \times \alpha^2$ as explained in annex A.

This term, on the other hand, varies strongly with the distance D. Luminances are in proportion to D^{-2} (see equations 7 and 8) and α^2 is in proportion to D^{-2} for a longitudinal road markings and to D^{-3} for tranverse road markings (see section 5.3).

The total variation is proportional to D^{-4} or D^{-5}, so that the visibility level increases steeply as a driver approaches a road marking. This is experienced in the way that road markings are invisible at a long distance, but emerge at closer range.

This feature is enhanced when driving on low beam, as road markings further away than the cut-off are mostly not visible.

5.4.3 Daylight illumination and road lighting

The luminance L measured in $cd \cdot m^{-2}$ at some point of a road marking or a road surface in diffuse illumination is calculated by:

$$\mathbf{L = Qd \times E} \qquad \textit{(Equation 9)}$$

where	**Qd**	is the luminance coefficient in diffuse illumination measured in $cd \cdot m^{-2} \cdot lx^{-1}$.
and	**E**	is the diffuse illuminance at the point on the plane of the road marking or road surface measured in lx.

The luminance coefficient in diffuse illumination is defined in EN 1436, which also introduces a standard measuring geometry and classes of minimum Qd values.

The unit of Qd is in principle $cd \cdot m^{-2} \cdot lx^{-1}$, but for the same reason as for the R_L, the one thousand times smaller unit of $mcd \cdot m^{-2} \cdot lx^{-1}$ is used.

The standard measuring geometry is defined by the value of the observation angle α of 2,29° (the same value as for R_L). The Qd value does not change much with the observation angle α and may be applied to some approximation for a range of distances and for different vehicles.

For the dry condition, EN 1436 provides classes of minimum Qd values of 100, 130 and 160 $mcd \cdot m^{-2} \cdot lx^{-1}$ for white road markings and classes of minimum Qd values of 80 and 100 $mcd \cdot m^{-2} \cdot lx^{-1}$ for yellow road markings.

Road surfaces in the dry condition have Qd values in the range from 50 to 100 $mcd \cdot m^{-2} \cdot lx^{-1}$, or even higher. The lower end of the range applies for asphaltic road surfaces with dark stone aggregates, while the upper end of the range applies for asphaltic road surfaces with lighter stone aggregates and cement concrete surfaces.

Diffuse illumination is an approximation to daylight illumination in cloudy conditions, and to road lighting as an average for different locations on the road surface.

Daylight in cloudy weather is to levels of more than 10.000 lx in full daylight, and perhaps to 1.000 lx in weak daylight such as in wintertime in Nordic countries. In twilight, the level may be 100 lx down to zero. This means that the road surface will have typical luminance values of 1.000, 100 and 10 $cd \cdot m^{-2}$ in such cases.

With the high background luminances of daylight, visibility conditions are sometimes in the domain of **Weber's law** as explained in annex A. This is experienced in the way that road markings are not visible at any distance, if the contrast is too small, otherwise they are visible at almost any distance.

Road lighting for traffic routes is actually designed for the road surface luminance. Levels used in Europe are in a narrow range from 0,5 to 2 $cd \cdot m^{-2}$, with 1 $cd \cdot m^{-2}$ being typical. Road lighting for domestic roads is typically to a lower level, producing a road surface luminance down to about 0,1 $cd \cdot m^{-2}$.

In these cases, the contrast of the road marking to the road surface can be evaluated to some approximation by means of the Qd values, this leading to C = (Qd[road marking]-Qd[road surface])/Qd[road surface]. Contrasts are typically of the order of unity for worn conditions, but may be much lower in some cases.

A reason for the rather low contrasts is that the Qd value includes not only the diffuse type of reflection (reflection inherent in the colour of the surface), but also a component due to specular reflection. This component depends on the texture of the surface, but is often relatively strong, accounting for Qd values of for instance 20 to 40 $mcd \cdot m^{-2} \cdot lx^{-1}$.

In rainy or wet conditions, the specular component increases while the diffuse type of reflection decreases. The contrast will mostly stay positive, but may depend strongly on surface texture.

In directional illumination, as opposed to diffuse illumination, a more detailed calculation is required involving more data for the reflection properties. This is the case for other types of daylight, in particular when the sun is out. For a detailed analysis of road lighting, refer to CIE report No. 30.2, Calculations and measurement of luminance and illuminance in road lighting, 2nd ed., 1982.

5.5 Examples of application

In this section, the function representing the variation of the visibility distance D, of different kinds of road markings with different quality is shown, under headlamp as well as daylight illumination.

5.5.1 Headlamp illumination

Figure 5.1 shows visibility distances D for road markings in the illumination by two headlamps with a luminous intensity typical of the high beam.

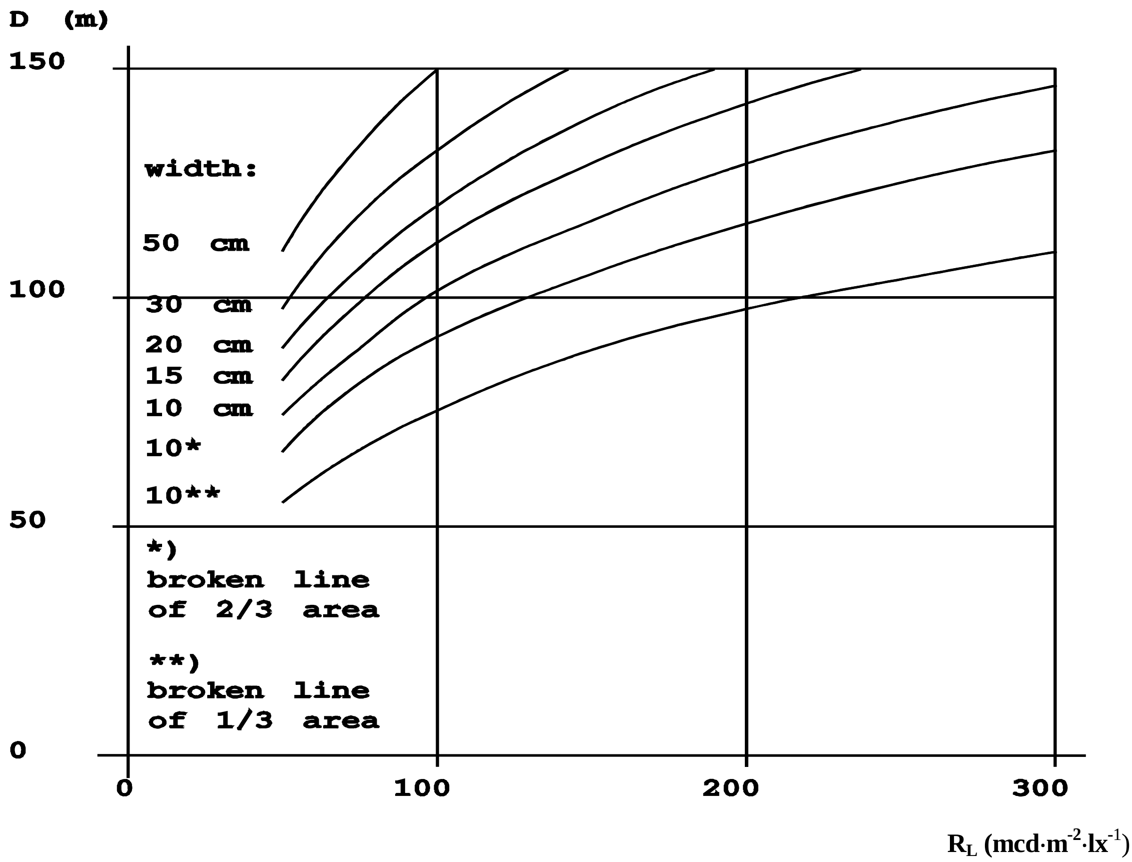


Figure 5.1 - Visibility distance D for longitudinal road markings in high beam illumination.

As a simplification, the luminuous intensity is assumed to be constant in directions towards the road markings. The intensity value is 10.000 cd.

The visibility distance is given as a function of the R_L value in a range from 50 to 300 mcd·m^{-2}·lx^{-1}, corresponding to quite low up to relatively high reflectivities of road markings in the worn state. The road surface is relatively dark, as simulated by an R_L value of 15 mcd·m^{-2}·lx^{-1}. Contrast is therefore given by **C = (R_L[road marking]-15)/15**.

The parameter of the figure is the geometry of the road marking. These are continuous lines of widths 10, 15, 20, 30 and 50 cm, and broken lines of width 10 cm with markings filling 2/3 and 1/3 of the distance along the road (proportions of marking to gap lengths of respectively 2/1 and 1/2). From the figure, it can be seen that a broken line results in the same visibility distance as a continuous line of a reduced width (those reduced widths are respectively 6,67 and 3,33 cm). In the same way, results for continuous lines are representative also for broken lines of greater width.

Figures 5.2 and 5.3 show visibility distances obtained on the same basis as for figure 5.1, except that the luminous intensity of the headlamps is typical of the low beam. The luminous intensity is 10.000 cd for directions towards points up to a certain distance, and from there onwards only 1.000 cd owing to the cut-off.

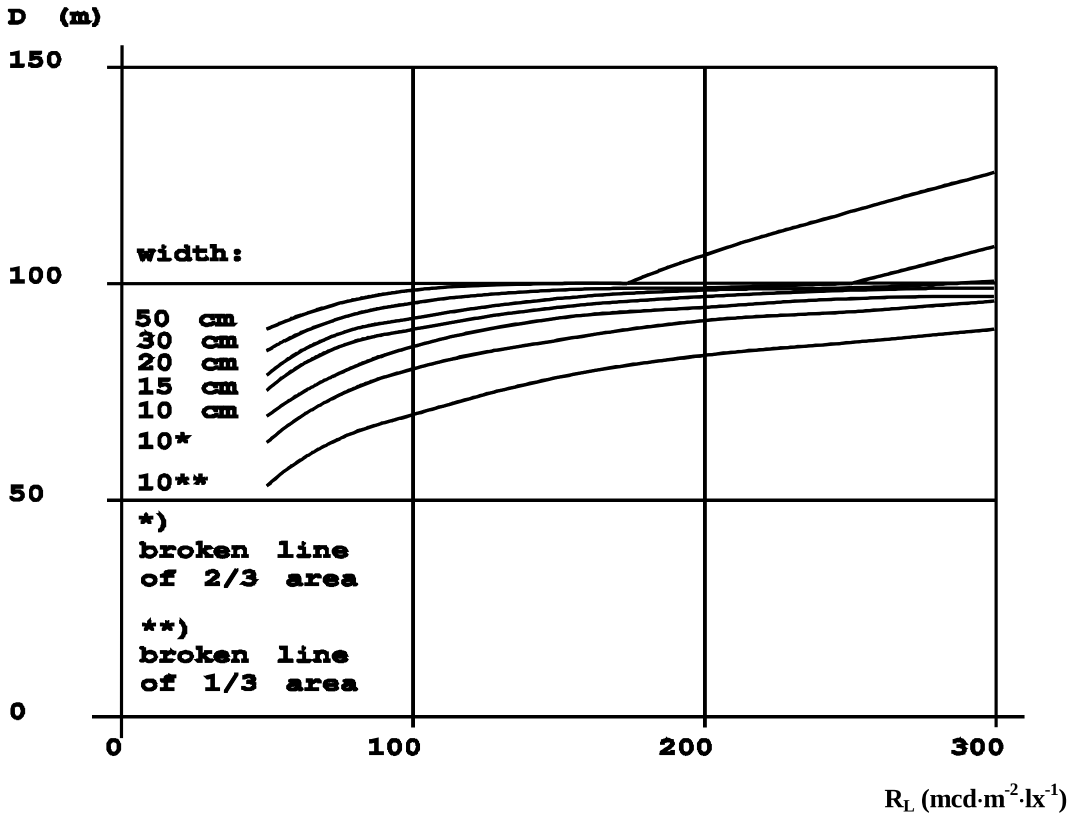


Figure 5.2 - Visibility distance (D) for edge lines in low beam illumination.

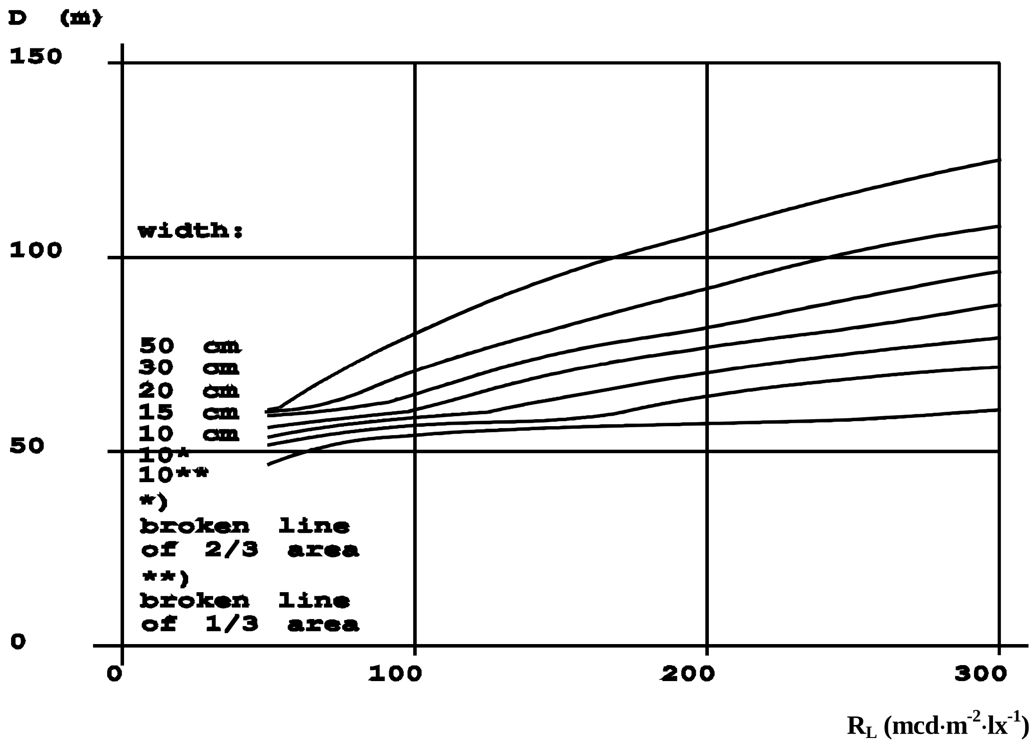


Figure 5.3 - Visibility distance (D) for centre lines in low beam illumination.

The elevated part of the low beam causes the distance to the cut-off to depend on the location of the road markings relative to the vehicle. The distances have been set to 100 and 60 m for figures 5.2 and 5.3 respectively with 100 m being typical for an edge line and the 60 m distance being typical for a centre line.

All three figures show an increase in the visibility distance with increasing width and/or R_L value of the road marking. For the high beam (figure 5.1), the increase is smooth. For the low beam (figures 5.2 and 5.3), the slope of the curves is affected by the need for a large width and/or a high R_L value to make the line visible in the low illumination beyond the cut-off.

The figures apply for young drivers in situations without glare from oncoming cars. As the road surface luminance is quite low, age and glare will affect results considerably. This may be considered by means of the methods in annex A.

5.5.2 Daylight illumination and road lighting

Figure 5.4 shows the visibility distance for a continuous road marking of 10 cm width in uniform illumination. The figure is established for young drivers in situations without glare.

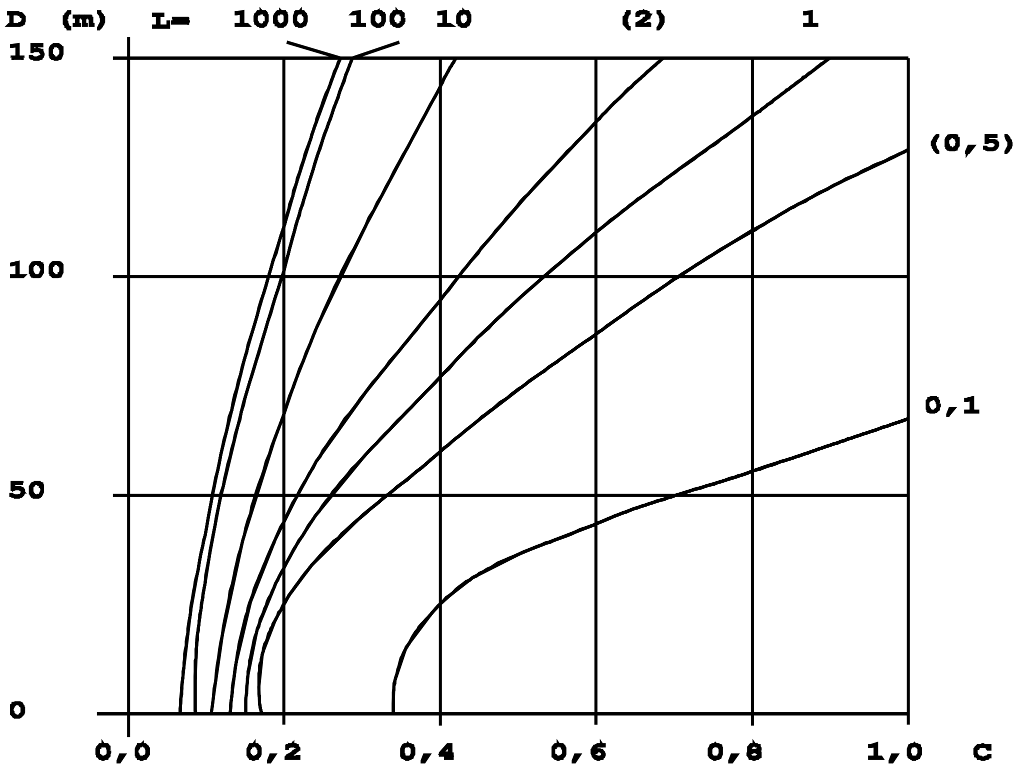


Figure 5.4 - Visibility distance (D) for a continuous road marking of 10 cm width in uniform illumination.

The visibility distance is given as a function of the contrasts C of the road marking to the road surface in the range from zero to unity.

For cases where contrasts may be evaluated in terms of Qd values, the Qd of the road marking ranges from the Qd of the road surface up to twice that value (see section 5.4.3).

The parameter of the figure is the lighting level in terms of the road surface luminance. The lighting levels correspond to a wide range from full daylight down to the lowest level of road lighting. The general levels of road lighting are fixed as a compromise between adequate visibility conditions on one hand, and expense and energy comsumption on the other. The precise level of road lighting in the rather narrow range used for traffic routes does influence the visibility of road markings (and of other objects), both directly and indirectly by means of the importance of glare, criteria for the selection of the level are based on such matters.

A curve for a given lighting level starts at a critical contrast, where the visibility distance is zero. From there onwards, the curve slopes upwards to indicate increasing visibility distance with increasing contrast.

The curves for the two highest lighting levels of 1.000 and 100 $cd{\cdot}m^{-2}$ (full and weak daylight respectively) are fairly close. At these levels, the human eye works close to its optimum, and the level itself does not strongly affect the visual performance.

At lower lighting levels, on the other hand, the curves change more and more, indicating lower visual performance.

At 10 $cd{\cdot}m^{-2}$ (twilight and perhaps very high levels of road lighting), performance is still relatively good. At 1 $cd{\cdot}m^{-2}$ (typical road lighting of traffic routes), performance is significantly reduced, while at 0,1 $cd{\cdot}m^{-2}$ (low level of road lighting of domestic roads), performance is strongly reduced.

The influence of the lighting level affects the engineering aspects of creating visibility of road markings (and of other objects).

From figure 5.4 it can be concluded that for high levels of daylight, the visibility of road markings is poor only when the contrast is very low. In consequence the engineering aim should be to avoid low contrast of road markings with important implications for traffic safety. We must take into account that very poor contrast in daylight may occur when the sun is ahead, and the road marking has less specular reflection than the road surface. This does happen for profiled road markings and may happen for other road markings, when the road surface has strong specular reflection.

On the other hand, for the level of road lighting used for traffic routes, the aim should be to supply enough contrast of road markings by means of a sufficiently high Qd value, and perhaps to avoid either a strong component of illumination in specular directions or the use of road markings with less specular reflection than the road surface. Due to the fact that the lowest level of road lighting is on the border to the even lower levels of headlamp illumination, the contrasts must be quite high to guarantee sufficiently high visibility distance (refer to section 5.5.1).

The optimum conditions in daylight means that elderly drivers have almost as good visual performance as young drivers, and that glare from man-made sources is negligible. The sun itself, on the other hand, may cause strong glare, either directly or by reflections in the road surface.

The effects of age and glare, in particular glare from headlamps of opposing vehicles, are not negligible at the levels of road lighting; they may be evaluated by the methods in annex A.

Figures 5.5 and 5.6 show a more detailed analysis of visibility distance for the two levels of road lighting previously described (1.000 and 1 $cd{\cdot}m^{-2}$, respectively). Both are established for young drivers in situations without glare. The parameter of the figures is the road marking geometry with the same cases as in figures 5.1, 5.2 and 5.3.

From the figures, it can be seen that the road marking geometry is more important for the lower lighting level of 1 cd·m^{-2} (typical road lighting of traffic routes) than for the higher lighting level of 1.000 cd·m^{-2} (full daylight).

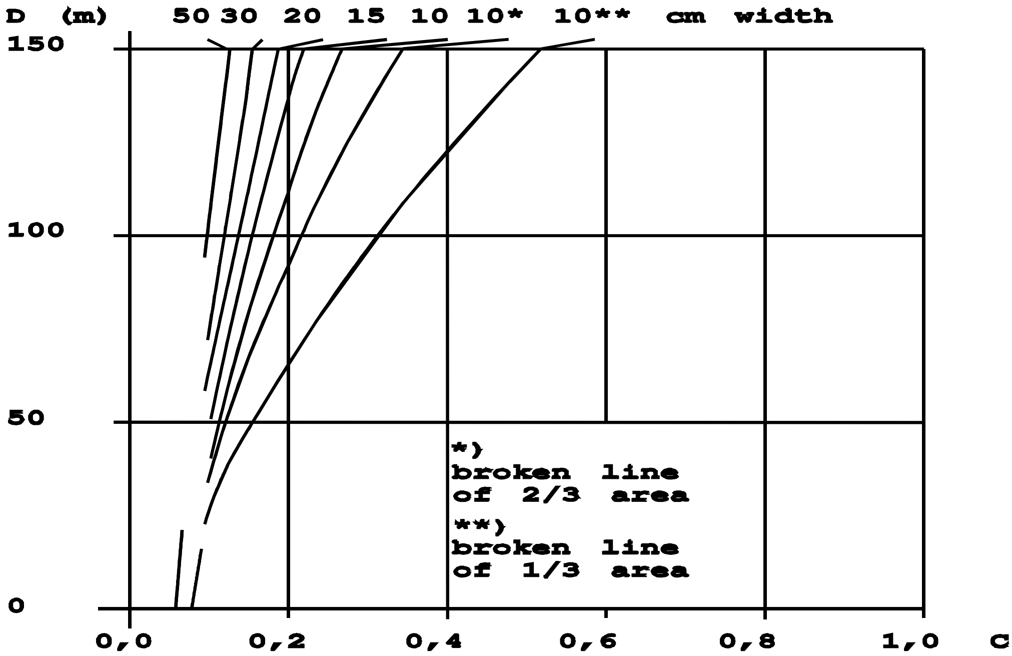


Figure 5.5 - Visibility distance (D) for longitudinal road markings in full daylight (1.000 cd·m^{-2} of road surface).

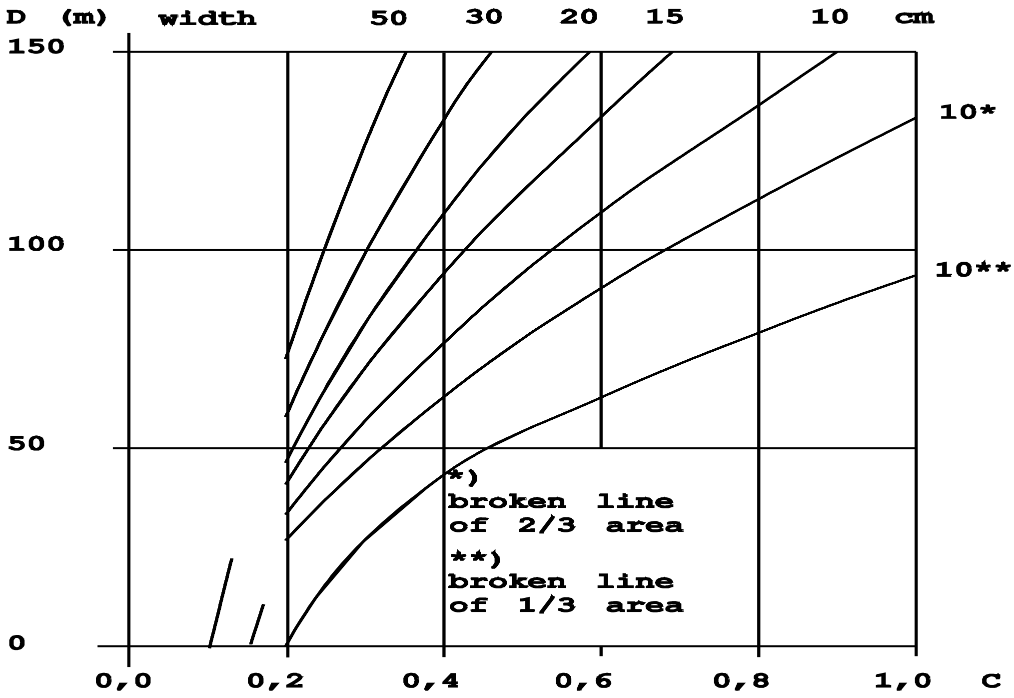


Figure 5.6 - Visibility distance (D) for longitudinal road markings in typical road lighting for traffic routes (1 cd·m^{-2} of road surface).

5.6 Validity of the calculation model

The validation of the calculation model depends basically on two methods of transforming from the road situation to the simple laboratory situation.

The first method, described in section 5.3, concerns the calculation of the equivalent target size of a road marking by luminance weighted integration over the surface of the road marking. The second method, described in section 5.4, concerns the selection of the target and background luminances in cases of non-uniform luminance.

For headlamp illumination, visibility conditions are in, or close to, the domain of **Ricco's law**, where the critical issue is to account for the total stimulus to the eye (refer to section A.5, in Annex A).

The methods are correct in this respect, this being the reason that the methods work well for the situations of the driving experiment accounted for in annex B, involving longitudinal lines and headlamp illumination. It may be expected that the transposition will work well for all cases of headlamp illumination.

In daylight illumination, the road marking and the road surface will normally have uniform luminance. Therefore, the second method of selecting the luminances will obviously provide correct results, and only the first method needs to be considered.

In this case, the first method is based on the assumption that the shape of the target is not important, as long as the size of the target, measured in total solid angle, is accounted for.

Such a statement is not correct in general. However, in conditions of full daylight, the visibility of road markings is poor only when the contrast is poor, so that the domain of **Weber's law** applies (refer to section A.5, in Annex A). The critical factor is then the contrast itself, while the size and shape of the target has less influence.

Neither of the methods are then critical for conditions of full daylight. In conditions of weak daylight, such as at dawn or dusk, the domain of Weber's law will no longer apply. Hence the first method involves some approximation.

Conditions of road lighting are similar to those of weak daylight conditions, as the luminance will be roughly uniform and the lighting level relatively low.

The above mentioned approximation probably leads to a too-negative estimate of visibility, as targets of non-circular shape are mostly more visible than circular targets.

In total, the calculation method may be assumed to work to a sufficient engineering accuracy for the cases relevant for road markings.

Chapter 6. Drivers' Needs of Preview Time

6.1 Introduction

The aim of the experiment reported in this chapter is to acquire basic data on drivers’ needs or demands for visibility of road markings at night.

The driver must be able to see the road in front of the car at a certain minimum distance or preview time in order to keep the car under full control in the driving lane.

This problem is difficult to solve by carrying out full-scale experiments on real roads or test tracks. This is because the visibility distance or the preview time to road markings cannot be well controlled, for at least two reasons:

- First, the driver’s visibility of the road is uncertain beyond a certain distance because of the absence of strong visual cues in this area.
- Second, visual performance varies between drivers, which implies that what can be seen by one driver cannot be seen by another.

Therefore, very little solid empirical evidence can be found in the literature, although preview times in the range from 2 to 5 seconds have been proposed.

One possible approach to overcome this difficulty is to carry out experiments in a driving simulator in which the picture of the road scene is generated by a computer. The driving simulator of the Swedish Road and Transport Research Institute (VTI) was used for the study. The information to the driver from the simulated road scene is therefore under total control of the experimenter. Using this technology the road scene is shown to the driver up to a specified distance, beyond which no visual information is available.

Therefore, in this part of the COST 331 research it was intended to provide an answer to the following question: "*What visibility distance or preview time to the visibility limits of road markings does the driver require in order to keep the car under full control in the driving lane?*"

It should be noted that this task is neither to find the most comfortable nor the safest level of the driver’s visibility of road markings, but only the minimum preview time needed for safe driving.

In order to answer this question, as stated above, an experiment was carried out in the VTI driving simulator. The description of the experiment, its results and the most relevant resulting conclusions are presented in the following sections of this chapter.

6.2 Methodology

6.2.1 Work plan

Work started in January 1997 with the development of supplementary hardware in order to generate a high quality picture of a night driving scene. Parallel to this work the simulated route was programmed. This program also allows quick changes between two conditions of speed (driver’s free choice of speed and 90 km/h set by a cruise control) as well as a random order of presentation of the levels of visibility of the road.

Measures of driver behaviour when driving the route are the dependent variables.

The overall experimental situation and the picture of the driving scene were tested in a number of pilot trials before summer. The exact procedures and conditions for the experiment were fixed early in August. The experiment was then carried out in late August and beginning of September.

6.2.2 Equipment

The equipment used was the **driving simulator** developed by the Swedish Road and Transport Research Institute (VTI). The driver or test subject in the simulator "drives" a Volvo 850 saloon with automatic transmission. The car is simulated by a "mock up" with the bonnet and windscreen and with the original interior of a Volvo 850 from the front up to a point behind the driver's seat. This mock up is mounted on a moving base with mainly transverse movement that makes the driving simulator especially valid for driving through curves and for making quick lane changes. The performance and driving qualities of the car in the simulator correspond well with a Volvo 850 on the road.

The road scene in front of the driver is presented on a screen in front of the car by three video projectors. This screen has a visual angle of 120° seen from the driver's seat (figure 6.1).

The video technique also has limitations. The maximum range of luminances in the video picture on the screen is very small compared to luminances in the road scene under real driving conditions. Furthermore, the resolution of the picture is considerably lower compared to normal eyesight. These limitations have consequences for what the driver's visual tasks in the simulator should be. It follows that all visual stimuli on the screen need to be clearly visible.

Figure 6.1 - The driving simulator

6.2.3 Dependent variables

Condition of free choice of speed

- Driving speed
- Lateral position of the car in the driving lane
  - Lateral position in the driving lane
  - Extreme lateral position in the driving lane
  - Standard deviation of lateral position
  - Distance driven outside road marking

Cruise control condition (90 km/h)

- Lateral position of the car in the driving lane
  - Lateral position in the driving lane
  - Extreme lateral position in the driving lane
  - Standard deviation of lateral position
  - Distance driven outside road marking

6.2.4 The simulated road scenario

The road simulated had two lanes. The lane width was 3,5 m measured from the centre of the road to the outer edge of the edge line. The road marking modules selected correspond to the Swedish rules for application of centre and edge lines. The centre of the road was marked with a broken centre line (3 m long marks with 9 m gaps, equivalent to modules of 12 m). The outer edges of the driving lanes were marked with broken edge lines (1 m long marks with 2 m gaps, equivalent to modules of 3 m). The width of the road markings was 0,14 m.

Continuous edge lines were compared with broken edge lines in pilot tests. As broken edge lines gave a more valid perception of motion and speed in the simulator, this type of edge line was chosen for the experiment. The reason for choosing lines somewhat wider than 0.10 m was to compensate for the limited resolution of the video technique.

The road scene shown on the screen was a driving situation at night in which the road was exclusively shown by its centre and edge lines. There was no other contrast in the picture, either between the road surface and the environment or in the environment itself. So there was no complementary visual information beside the road markings in the computer-generated picture (figure 6.2).

The simulated road had horizontal curves and a straight stretch of road between curves. There were therefore no "S-curves" or vertical curves. The road was shown on a screen in front of the car (mock up) and in a correct perspective from a driver’s point of view.

The subjects drove a route a number of times. The route was created by a number of curved sections and a number of straight stretches of road. Each specific curve section was specified by turning direction, radius and length. Each straight section was specified by its length.

The curved sections and the sections of the straight stretches were selected in random order, using a computer, for each drive of the route. Therefore, the route had a constant length (sum of length of all sections was 5000 m) but it was also unique for each drive.

Figure 6.2 - The road scene (the numbers in the right corner show the visual distance in metres).

The test road consists of 16 curves preceded and followed by straight stretches of road.

The simulated road scenario can be summarised as follows:

- Two lane road
- Lane width: 3,5 m
- Centre line: 3 m long road markings with 9 m gaps
- Edge line: 1 m long road markings with 2 m gaps
- Only horizontal curves on the route (no S-curves or vertical curves)
- Every curve preceded by a straight stretch of road

- Length of straight stretches of road, 4 levels: 100 m, 110 m, 140 m and 180 m
- Curve radii (varied by a factor 1,5), 4 levels: 200 m, 300 m, 450 m and 675 m
- Length of curves, 4 levels: 120 m, 130 m, 140 m and 150 m
- Total length of the route (simulated road): 5.000 m
- Number, type and radii of curves (see table 6.1)

Table 6.1 - Description of curves designed for the experiment

Radius (m)	Transition curve		
	Yes	No	Σ
200	4	0	4
300	2	2	4
450	2	2	4
675	0	4	4
Total number	8	8	16
The radius for the transition or clothoid curves decreased down to the constant radius over a transition distance of 20 m.			

6.2.5 Visibility conditions

The general road scene is a two-lane road at night without opposing traffic. Sight distance of the road ahead (controlled by making the road markings visible) is varied (by a factor of 1,5) in 5 levels: 20 m, 30 m, 45 m, 67 and 100 m.

The luminance of the road markings ahead is varied for every visibility distance in the following way: 100 % luminance for the nearest half of the sight distance available. From that distance the luminance continuously decreases to 30 % of its original luminance at the limit of the available sight distance. There is therefore a sharp cut-off at the end of the sight distance, beyond which there are no cues of the road at all (this situation simulates a symmetric European dipped headlight with no light above a very sharp cut off). The road markings were clearly visible to the subjects throughout the sight distance but there was no visibility beyond this distance.

6.2.6 The driving task

Two conditions of driving speed were selected for the experiment. In the first condition, the subject has free choice of speed by the normal use of the accelerator. The subjects were instructed to drive as they normally would under these sight conditions and to keep the car in their driving lane. There is feedback through the steering wheel while driving on centre and edge lines (this feedback is similar to that received in real driving when driving on longitudinal broken 3-4 mm high thermoplastic road markings).

In the second condition, the subjects drive with the cruise control set at a constant speed of 90 km/h. In the latter condition the subjects were instructed to keep the car in their driving lane and not to use the brakes.

6.2.7 Subjects

The subjects were 24 experienced drivers in two age groups: 25-35 and 55-65 years of age with an equal number of men and women: 6 young men, 6 young women, 6 older men and 6 older women.

6.2.8 Interview with questionnaire

The subject filled in a questionnaire after the experiment in order to collect information about driving experience. In the questionnaire the following information was asked for:

- Age
- Sex
- Number of years with driver's licence
- Kilometres usually driven per year
- Kilometres driven during last year
- How often the subject drives in the dark during the dark season (winter). Alternatives: 1. Several times a week, 2. Once a week, 3. Once a month, 4. Almost never.
- If the subject finds that s/he has a harder time driving in the dark than other people. Alternatives: 1. Yes, 2. No. If "yes" they are asked to fill in why.
- If the subject has driven the simulator before. Alternatives: 1. Yes, 2. No.

The information collected is presented in tables 6.2 and 6.3.

Table 6.2 - Group mean values regarding age, and driving experience.

Group	Age	Years with driver's licence	Distance driven per year [km]	Distance driven during last year [km]
Young female	30	12	11.500	10.000
Older female	59	36	8.500	7.100
Young male	29	11	23.750	23.330
Older male	62	44	20.670	17.330

Table 6.3 - Results from the question "how often the subjects drive in the dark during the dark season (winter)".

Group	Almost never (4)	Once a month (3)	Once a week (2)	Several times a week (1)
Young female			4	2
Older female	1	1	1	3
Young male		1		5
Older male	1		1	4

6.2.9 Procedure

Every subject is exposed to all experimental designed conditions. This means that each subject is his own "control" and that the number of subjects can be relatively small.

The experimental session begins with a verbal instruction followed by a practice drive in order to make the subject familiar with the driving situation. This practice drive is identical for all subjects, starting with the longest sight distance followed by successively shorter and shorter distances until the subject has been exposed to the 30-m level of visibility.

When the practice drive is finished and the subject's questions, if any, are answered the main experiment starts. The first condition is the driver's free choice of speed. The visibility distances are varied in 4 levels: 30, 45, 67, and 100 m. The subjects drive the 5 km long simulated road for each of these visibility conditions. These conditions are presented one at a time and in random order.

After this drive there is a short break and new instructions are given for the cruise control condition. This condition is somewhat extreme, with the range of visibility distance being shorter but also varied in 4 levels: 20, 30, 45, and 67 m. The procedures of the previous drive are then repeated at a constant speed of 90 km/h.

The "experimental session" can be therefore summarised, as follows:

1. Instruction
2. Training drive
   -Driving distance: 10 km
3. Main experiment

3.1 Condition of free choice of speed - Instruction
- One drive for each of the 4 sight distances, 30, 45, 67, and 100 m
- Driving distance: (5 km x 4 =) 20 km

3.2 Cruise control (90 km/h) condition - Instruction
- One drive for each of 4 sight distances, 20, 30, 45, and 67 m
- Driving distance: (5 km x 4 =) 20 km

4. Final interview with questionnaire

Time needed for the subjects to carry out the experiment was about 1 hour.

6.3 Analysis of the results

6.3.1 Choice of speed

When the driver has the possibility to choose speed he adjusts it to the sight conditions. Speed increases with visibility of the road marking ahead up to a distance of about 67 m. Above this distance there is no increase in speed. The speed (group of mean values) at free choice of speed is shown in table 6.4 and figure 6.3. Sight distance has a significant effect on speed ($F(3;69) = 55,4$; $p<0,001$). The test is based on a "within-subject-design". Paired samples test shows that there is a significant ($p<0,05$) difference in speed between all sight distances except between 67 and 100 m.

Table 6.4 - Mean speed and standard deviation (S.D) of speed between subjects at the different sight distances. (Group mean values).

Sight distance [m]	30	45	67	100
Mean speed [km/h]	60,3	71,3	76,3	75,3
S.D. of speed [km/h]	11,8	11,3	8,1	9,2

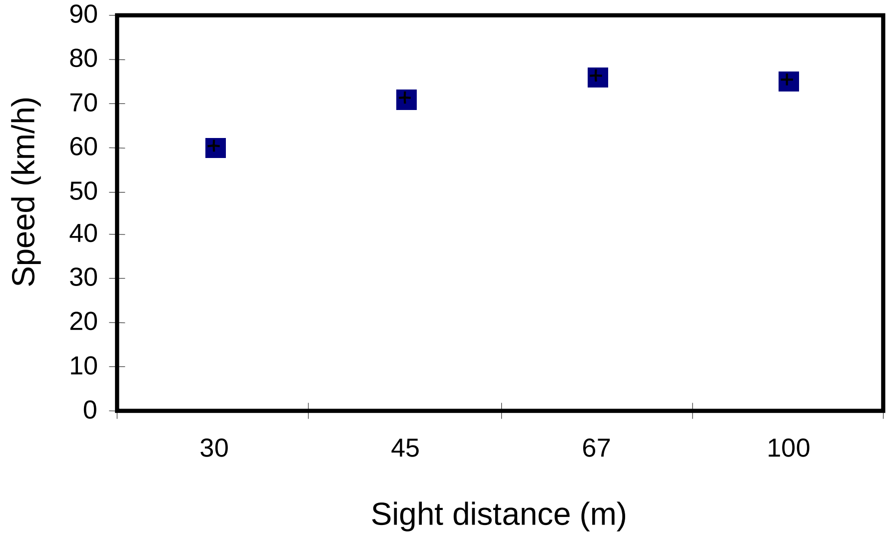


Figure 6.3 - Mean speed (km/h), at free choice of speed, for the four levels of visibility of road markings.

The speed is affected not only by sight distance but also by the radius of the curve. The smaller the radius, the lower is the speed. This can be seen in figure 6.4 which shows the average speed (group of mean values) for each radius with or without a transition, and for straight sections (10 m at the beginning and end are excluded from the average).

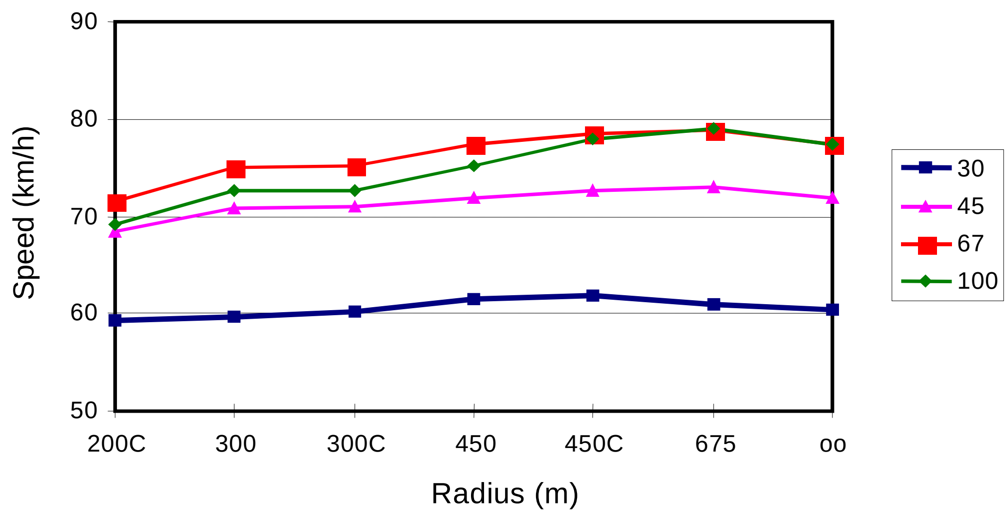


Figure 6.4 - Mean speed in curves and on straight stretches (C is for transition curves and oo is for straight sections).

In figure 6.5 the speed differences (group of mean values) between mean speed on straight sections and different curves are shown (10m in the beginning and end of every curve or straight stretch are excluded from the average). The driver reduces speed more at longer sight distances than at a short sight distance, when approaching a curve with a small radius. With the 30 m visibility distance and a short preview time (see clause 6.3.2) there is little time for adjustment of speed before sharp curves. Drivers cope with this situation by keeping a low speed with little variation in speed over the route. With longer visibility distances of road markings drivers have longer time to adjust speed to the curve they are approaching. There is a larger decrease of speed in sharp curves with increasing visibility distance of the road marking.

The average speed on straight sections is slightly lower than the speed in curves with large radius. This can be seen in figure 6.4 and is the cause of the negative differences in figure 6.5. This is because the speed on the straight sections is affected by the speed in the preceding and following curve.

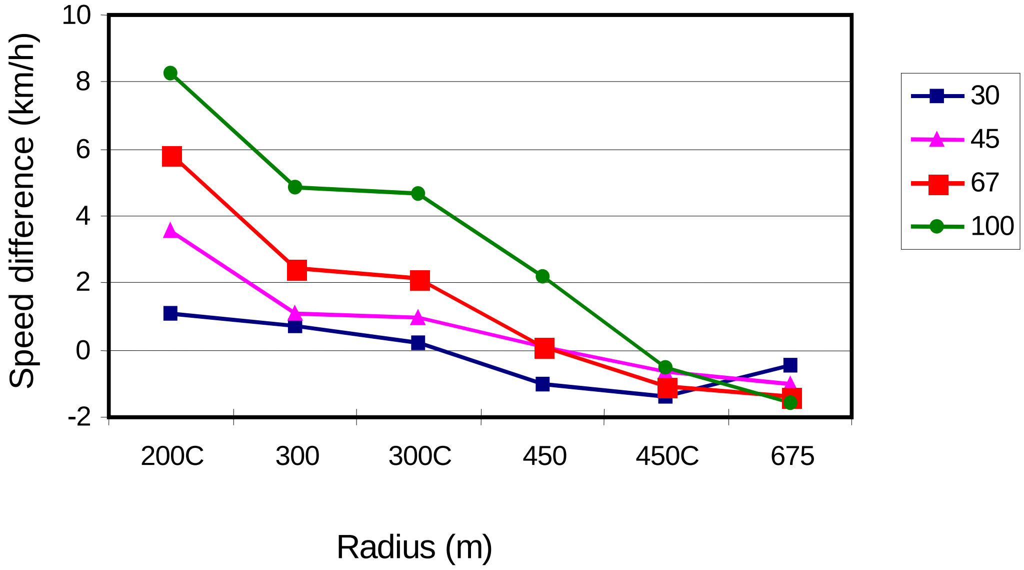


Figure 6.5 - Difference of mean speed on straight stretch and in curves at four levels of sight distance.

A second analysis of variance regarding sex and age showed no significant difference between men and women and no difference according to age.

6.3.2 Preview time

The preview time is the time it will take the driver to travel from the present location to the most distant road marking visible (see chapter 5). This is a useful variable because it takes both sight distance and speed into consideration. It is calculated by dividing the sight distance by the driving speed (table 6.5).

Table 6.5 - Preview time (group of mean values) at the different sight distances for both speed conditions: free choice of speed and cruise control (90 km/h).

Sight distance [m]	20	30	45	67	100
Mean speed at free choice [km/h]		60,3	71,3	76,3	75,3
Preview time at free choice [s]		1,8	2,3	3,2	4,8
Mean speed at cruise control [km/h]	90	90	90	90	
Preview time at cruise control [s]	0,8	1,2	1,8	2,7	
Note that the shortest preview time at the condition free choice of speed is 1,8 seconds. At the condition cruise control the same preview time occurs at 45 m sight distance.					

6.3.3 Mean lateral position

The lateral position is the distance in metres between the centre of the car and the centre of the road.

An Analysis of Variance was made for each of the two speed conditions, free choice of speed and cruise control. The “within-subject-design” of the experiment is considered in the analysis. The design of the analysis is as follows (table 6.6):

Table 6.6 - Selection of variables

Dependent variable	Independent variables (number of levels)
lateral position	*sight distances* (4) *radius (4)* *transition curves (2, with and without a clothoid)* *right or left (2)*
All curves with the smallest radius began with a clothoid, and all curves with the largest radius were entirely circular. This made the design non-symmetric.	

Free choice of speed

On straight stretches of road at the condition free choice of speed, variations in sight distance resulted in very little difference in lateral position (figure 6.6) Lateral position is defined here as the distance between the centre of car and the centre of road. 0 m lateral position is the centre line and 3,5 m is the outer edge of the right edge line (group mean values).

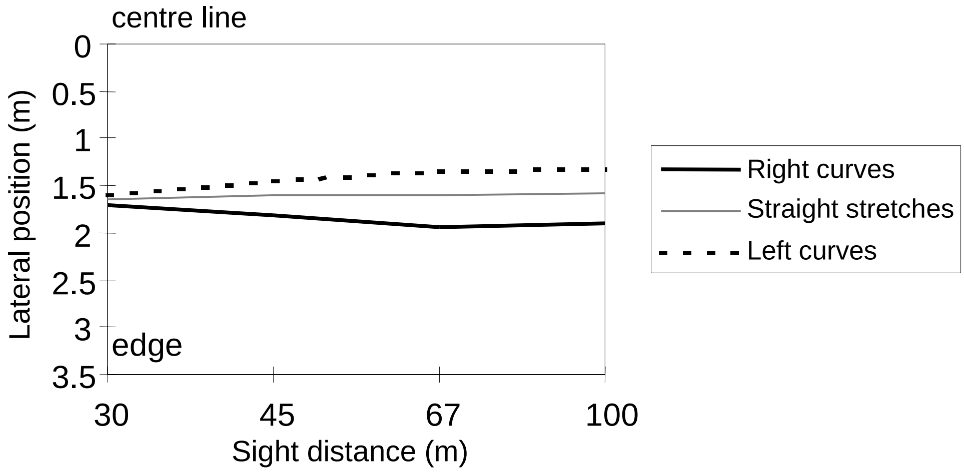


Figure 6.6 - Mean lateral position for right and left curves and straight stretches at the condition free choice of speed.

In right and left curves the driver behaves differently. In the right curve the *lateral position* is further to the right and in the left curve further to the left. The tendency is stronger for longer *sight distances* than for shorter. This might be because drivers are cutting the curves and cutting more at longer *sight distances*. The Analysis of Variance shows a significant interaction between *sight distance* and the direction of the curve, *right or left* (F(3;1465) = 144; p<0,001).

It is not very clear how *radius* affects *lateral position* but it seems that the smaller the *radius* the further to the right the car is positioned in a right curve, and the further to the left in a left curve. An Analysis of Variance shows that the interaction between *radius* and *right and left curve* has a significant effect on the *lateral position* of the car (F(3;1465) = 35,9; p<0,001). The evolution of the *lateral position* for different radii can be found in figure 6.7 with the different radii on the x-axis. Lateral position is the distance between the centre of car and the centre of road. Centre line at the lateral position 0 m, outer edge of right edge line at 3,5 m. Left curves are labelled (L), right curves (R). C stands for transition curve and oo for straight stretches (group mean values).

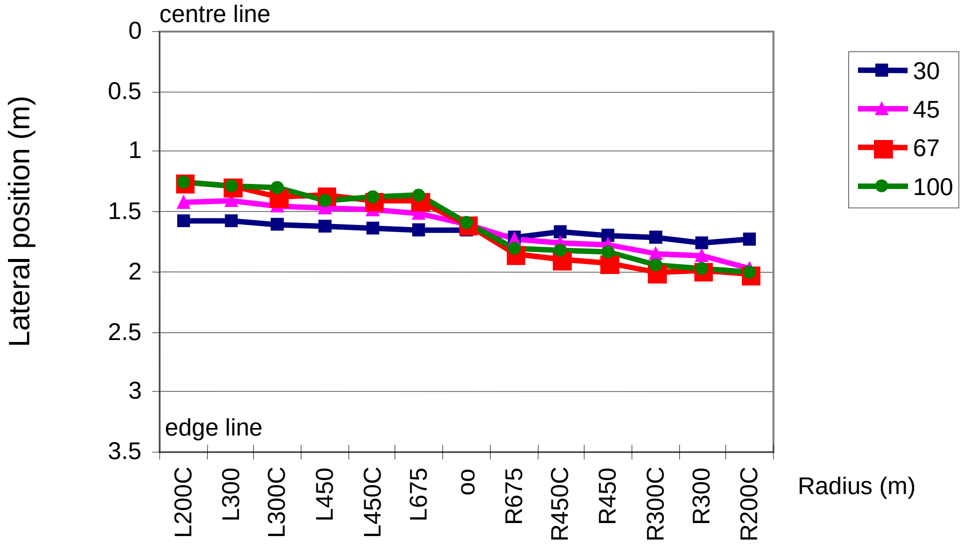


Figure 6.7 - Lateral position in every curve at the condition of free choice of speed at the four levels of sight distance.

The lateral position of each type of curve can be found in figure 6.8 with the sight distance on the x-axis. The centre line is at lateral position 0 m and the right edge of the edge line is at 3,5 m. The radii marked – are left curves. The radii marked C are with clothoid.

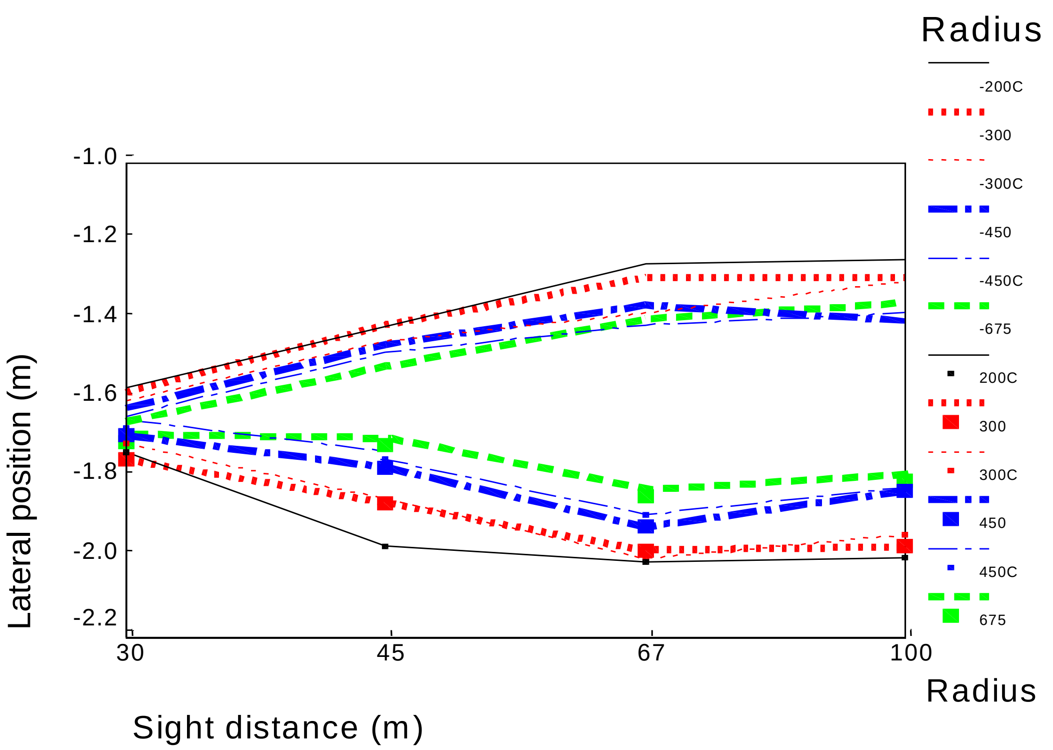


Figure 6.8 - Lateral position for each type of curve at the condition of free choice of speed.

It is not clear from the results of the statistical analysis whether transition curves have any effect on lateral position. Because of the non-symmetry, the possibility cannot be excluded that the effect of a transition curve is combined with an effect of radius.

Cruise control at 90 km/h

For the condition 90 km/h the lateral positions on straight stretches differ very little for different sight distances (figure 6.9). Lateral position is the distance between the centre of car and the centre of road. 0 m lateral position is the centre line and 3,5 m is the outer edge of the right edge line (group mean values).

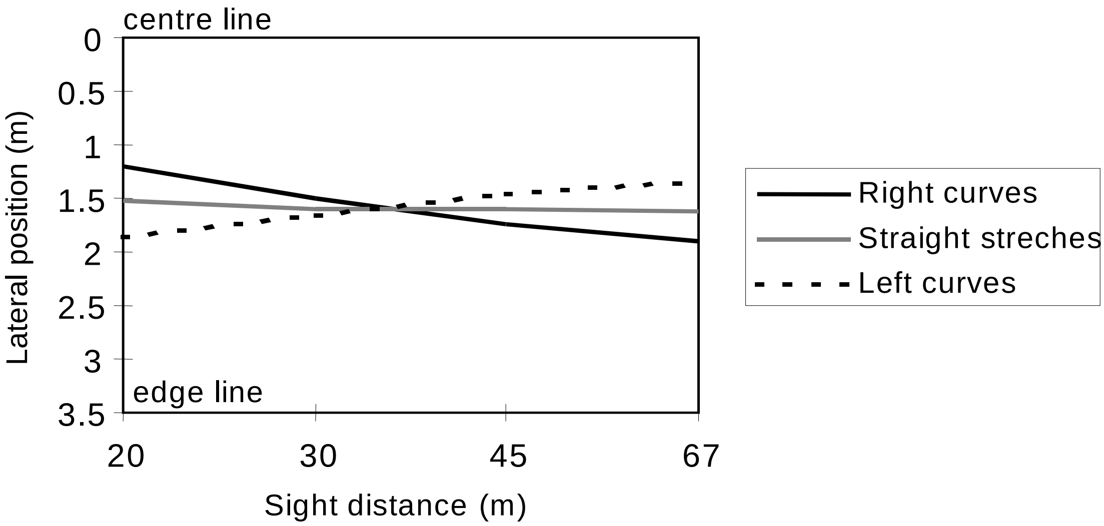


Figure 6.9 - Mean lateral position for right and left curves and straight stretches at the condition of cruise control.

For right curves, the longer the sight distance the further to the right is the driver's lateral position. In left curves, the lateral position is further to the left the longer the sight distance. At the two longer sight distances (45 and 67 m) the driver has a mean lateral position to the right of the position on the straight stretch and the other way around in left curves. This behaviour is similar to the condition free choice of speed and might be because the driver is cutting the curves. At the shorter sight distances (20 and 30 m) the lateral position in right curves is to the left of that on straight stretches. In left curves the lateral position is to the right compared to straight stretches. This could be because the driver is ”missing” the curve. The Analysis of Variance shows that the interaction between *sight distance* and *right or left* curve has a significant effect on *lateral position* ($F(3;1465) = 376,0$; $p<0,001$).

The effect of *radius* is not totally clear but for longer sight distances (45 and 67 m) there is a tendency for the lateral position to be further to the right in a right curve, the smaller the radius is. In a left curve the *lateral position* is further to the left the smaller the radius. This is probably because drivers are cutting the curves more at smaller radius. At the short sight distances (20 and 30 m) there is a tendency for drivers to ”miss” curves more the smaller the radius is. The Analysis of Variance also shows an interaction between *sight distance, right or left* and *radius* that has a significant effect on *lateral position* ($F(9;1465) = 6,1$; $p<0,001$). The effect of radius is illustrated by figure 6.10 with the different radii on the x-axis. Lateral position is the distance between the centre of car and the centre of road.

Centre line at the lateral position 0 m, outer edge of right edge line at 3,5 m. Left curves are labelled L, right curves R. C stands for transition curve, oo for straight stretches (group mean values).

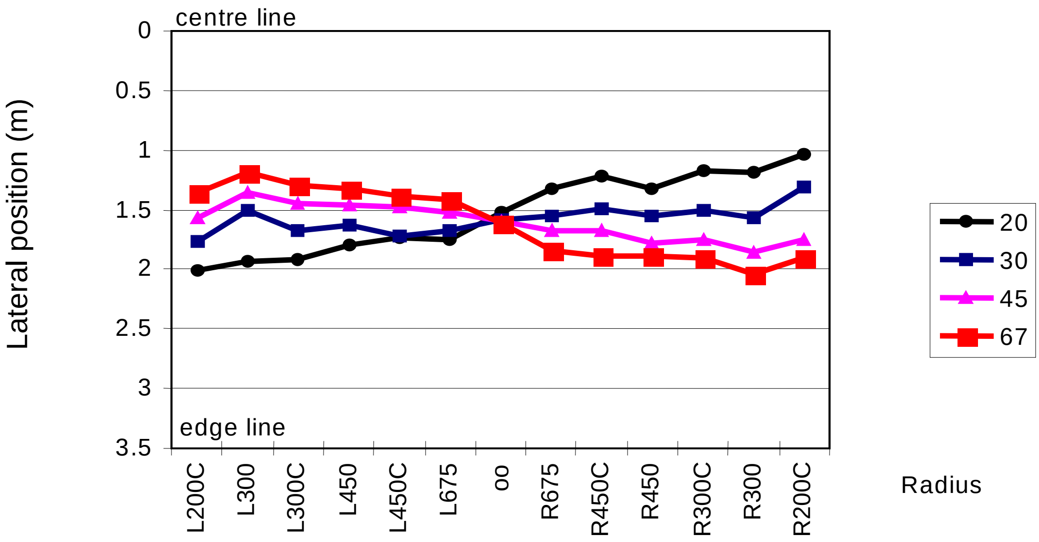


Figure 6.10 - Lateral position in every curve at the condition 90 [km/h] for different levels of sight distance.

The lateral position for each type of curve can be found in figure 6.11 with the sight distance on the x-axis. The centre line is at lateral position 0 m and the right edge of the edge line is at 3,5 m. The radii marked **(-)** are left curves. The radii marked C are with clothoid.

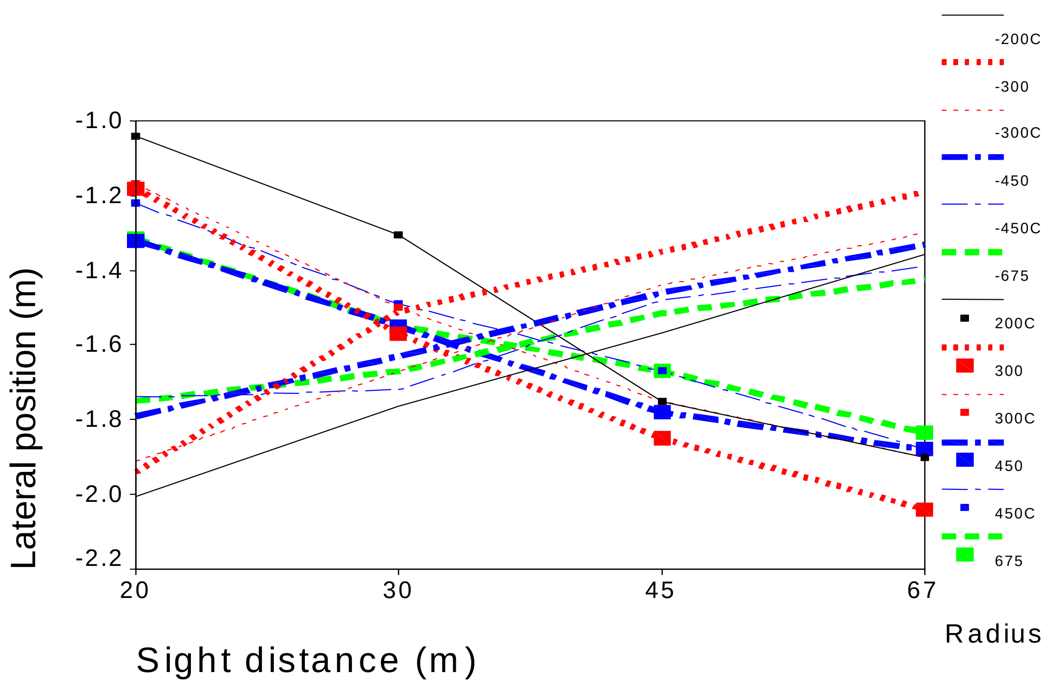


Figure 6.11 - Lateral position for each curve at the condition of 90 km/h.

Transition curves are not considered in the analysis for the same reason as for free choice of speed.

6.3.4 *Extreme lateral position in the curve*

The *extreme lateral position,* which is the lateral position of the right wheel when it is furthest to the right and the left wheel when it is furthest to the left, is measured for each test person in each curve. If just the *mean lateral position* is studied, this information is lost. It is the outside wheel in the curve that is most interesting to study. For instance, in a right curve it would be the lateral position of the left wheel that is furthest to the left. The *extreme lateral position* of the wheel is of interest because it shows how close the wheel gets to the edge or the centre of the driving lane in curves, and under what circumstances the driver "staggers" or "misses" the curve.

An important feature is that no systematic tendencies have been found for these extremes to occur in any particular part of a curve. Drivers seem to have very different ways of driving and lateral position also differs between curves.

An Analysis of Variance of the two extreme lateral positions in curves was made for right and left curves, with and without transition curves, i.e. four analyses, one for each extreme and for each speed condition. The “within-subject-design” is considered. The design of the analysis is as follows (table 6.7):

Table 6.7 - Selection of variables

Dependent variable	**Independent variables (number of levels)**
extreme lateral position	*sight distances* (4) *radius (4)*
extreme lateral position	*sight distances* (4) *transition curve* (2, with and without clothoid)

Free choice of speed

In right curves the minimum distance between the right wheel and the edge marking decreases with increasing *sight distance*. In left curves the effects are the same but in the reverse direction, that is the minimum distance between the left wheel and the centre line decreases with increasing *sight distance.*

For the condition free choice of speed, the outer wheel is closest to the outer road marking at the shortest sight distances. It can be seen from figures 6.12 and 6.13 that this is probably not hazardous. The shortest distance with the outer wheel to outer road marking is similar to that of the inner wheel when the curve turns in the other direction, and also probably similar to the mean extreme lateral position. This merely shows how the driver when the *sight distance* decreases lowers his speed to keep control. The *extreme lateral positions* (group of mean values) of the wheels are shown in figure 6.12 for curves without clothoids and in figure 6.13 with clothoids.

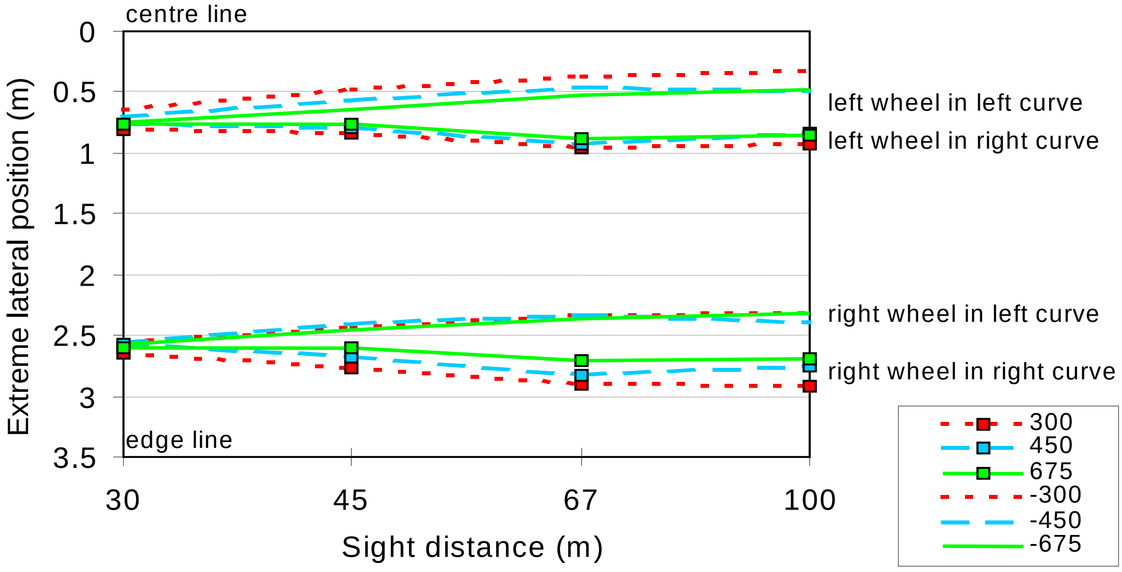


Figure 6.12 - Extreme lateral position of the outside wheel in curves without clothoids at the condition of free choice of speed.

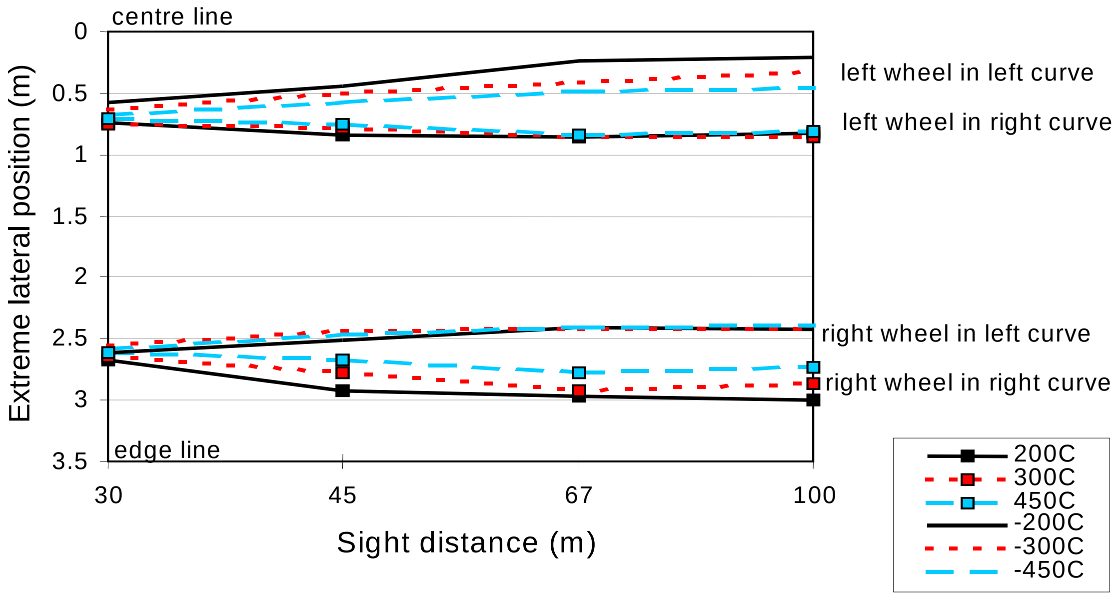


Figure 6.13 - Extreme lateral position of the wheel in the curves with clothoids at the condition of free choice of speed.

The centre line of the road is 0 m lateral position and 3,5m is outer edge of right edge line. There is one line for each radius. The lines with squares are right curves and the lines without are left curves.

The evolution of the extreme lateral positions (group mean values) of the wheels, but for right and left curves separated, are shown in figures 6.14 to 6.17. In all the figures, the centre line is at the lateral position 0 m and at the right edge line is at 3,5 m.

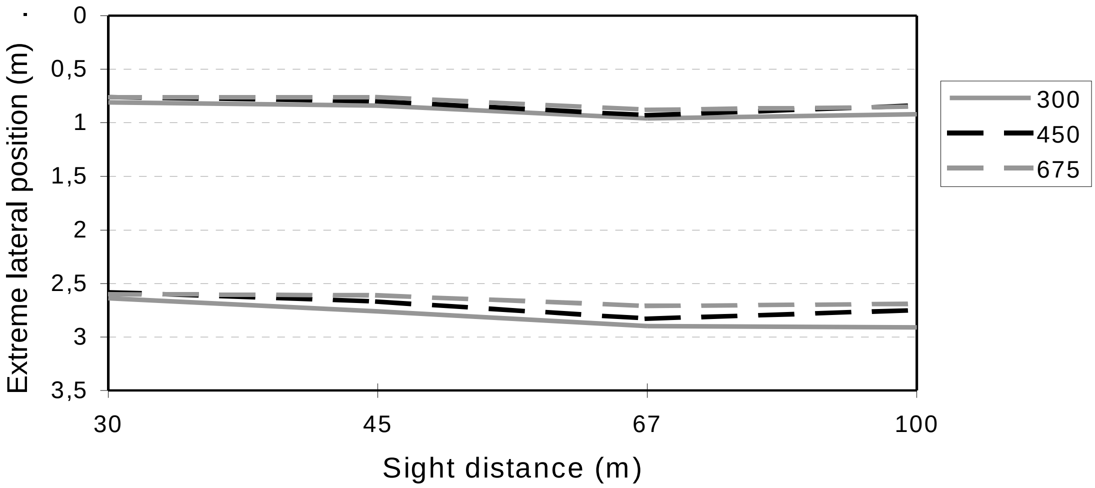


Figure 6.14 - Extreme lateral position of the wheels in right curve without clothoid at free choice of speed.

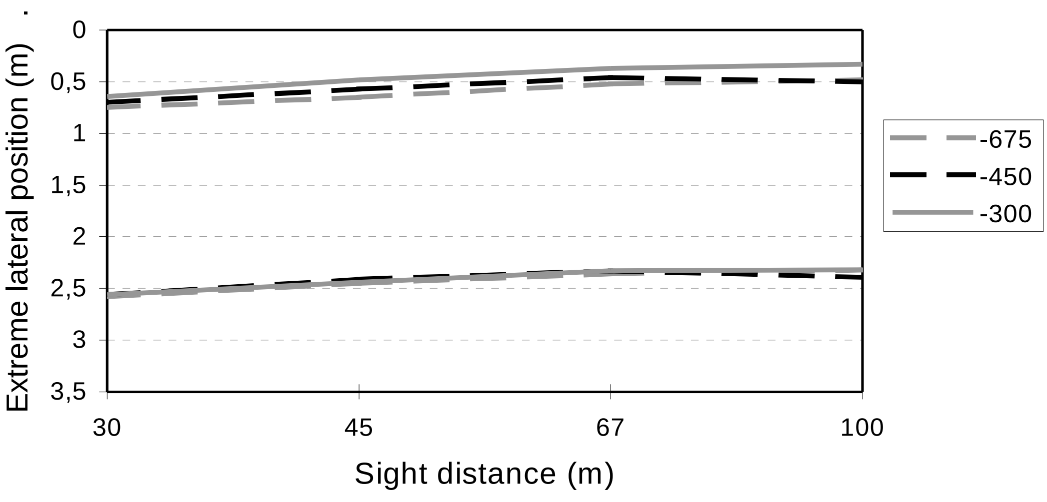


Figure 6.15 - Extreme lateral position of the wheels in left curve without clothoid at free choice of speed.

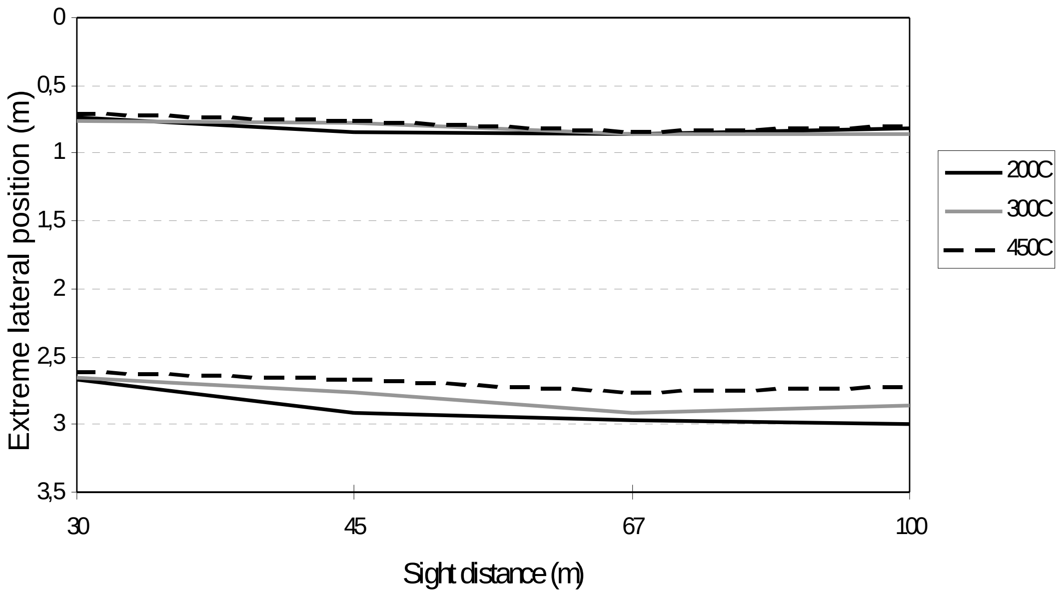


Figure 6.16 - Extreme lateral position of the wheels in right curve with clothoid at free choice of speed.

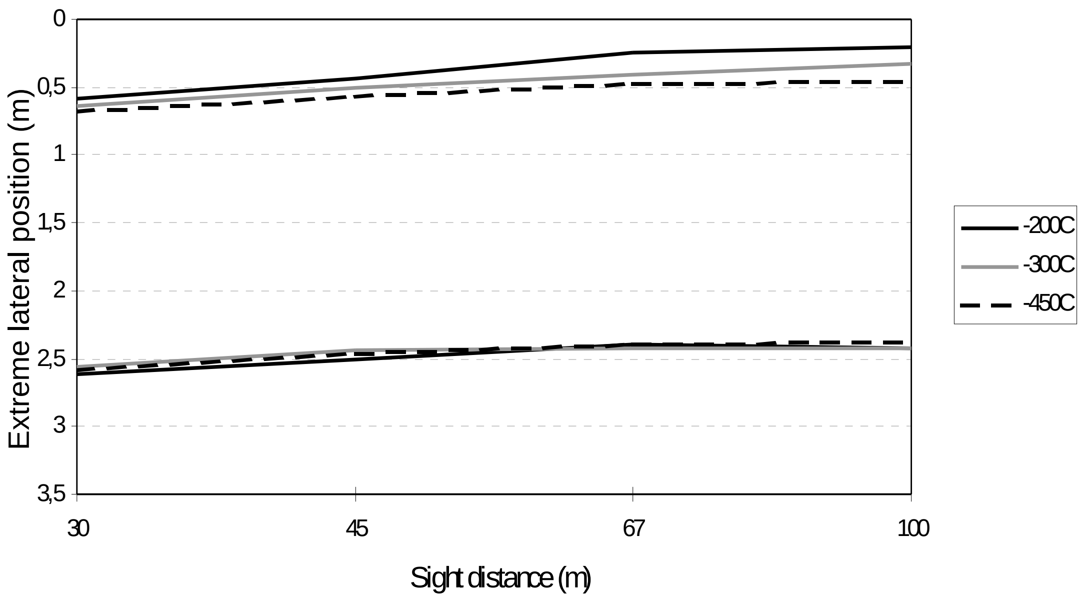


Figure 6.17 - Extreme lateral position of the wheels in left curve with clothoid at free choice of speed.

The main effect of sight distance on the extreme lateral position of the wheels on the outside of the curves are in all cases significant (F(3;49) = in the range of 10 to 48; p>0,001).

All results from the analysis of variance are included in table 6.8. The effect that sight distance (s), radius (r) or the interaction (s x r) have on the extreme lateral position is tested. The boxes for the outside wheel in the curve are tinted. Only effects significant at the 0.05 level are included.

Table 6.8 - Analysis of Variance for extreme lateral position at free choice of speed.

Clothoid	Curve	Wheel	df1	df2	Effect	F	p<
no	right	left	3	349	s	20,0	0,001
			2	349	r	9,7	0,001
no	right	right	3	349	s	31,1	0,001
			2	349	r	31,4	0,001
			6	349	s x r	2,7	0,05
no	left	left	3	349	s	58,9	0,001
			2	349	r	29,6	0,001
no	left	right	3	349	s	48,0	0,001
yes	right	left	3	349	s	10,3	0,001
yes	right	right	3	349	s	35,3	0,001
			2	349	r	41,9	0,001
			3	349	s x r	3,2	0,005
yes	left	left	3	349	s	46,1	0,001
			2	349	r	31,8	0,001
yes	left	right	3	349	s	16,5	0,001

Radius does not in general have a significant effect on the *extreme lateral position* of the outside wheel in curves. Nor is there any interaction.

When the two radii with and without *clothoids* are compared, it can be seen that the *extreme lateral position* of the outer wheel is further out in curves with *clothoids,* for right curves (F(1;353) = 19,6; p> 0,001) and for left curves (F(1;353) = 9,0; p< 0,005). There is no significant interaction with *sight distance*.

Cruise control at 90 km/h

For the condition cruise control also, it is mainly the *extreme lateral position* of the outside wheel in the curve that is interesting. There is a tendency at longer *sight distances* for the *extreme lateral position* of the outer wheel to occur further into the curve. It is probable that the driver is "cutting" the curve or allowing himself to "stagger". This is similar to what happened at the condition free choice of speed.

For the shorter *sight distances* the situation is the reverse, the *extreme lateral position* of the outer wheel moves out in the curve. This could be because the driver is "staggering" or "missing" the curve. This tendency is stronger the smaller the *radius* is. The interaction between *sight distance* and *radius* is, for all extreme positions of the outer wheel, significant (F(6;349) = in the range of 2,9 to 4,6; p>0,01). The *extreme lateral positions* (group of mean values) of the wheels are shown in figure 6.18 for curves without clothoids and in figure 6.19 with clothoids. The centre line has the lateral position 0 m and outer edge of the right edge line 3,5m. There is one line for each radius. The lines with squares are right curves and the lines without are left curves.

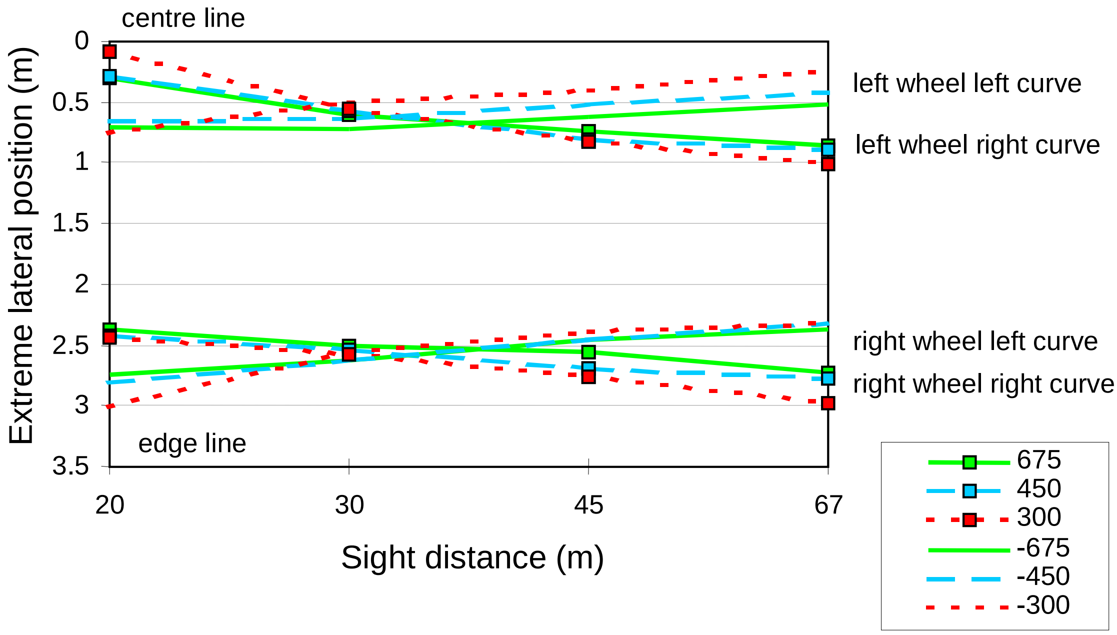


Figure 6.18 - Extreme lateral position of the outside wheel in curves without clothoids at the condition of cruise control.

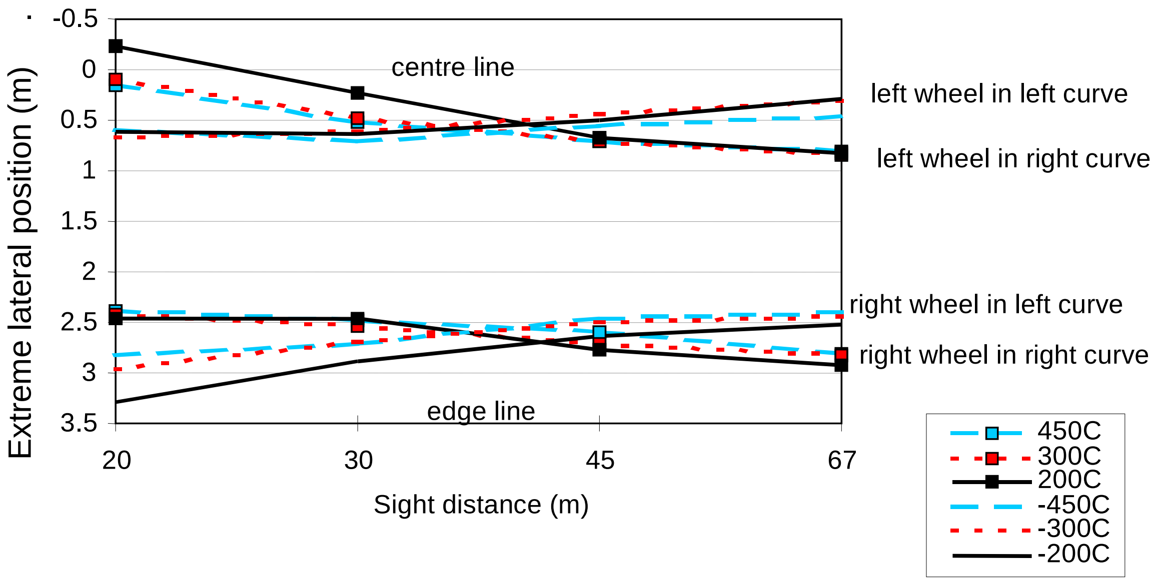


Figure 6.19 - Extreme lateral position of the wheels in curves with clothoid at the condition of cruise control.

The evolution of the extreme lateral position (group of mean values) of the outside wheels, but for right and left curves separated, are shown in figures 6.20 to 6.23. In all the figures, the centre line is at the side position 0 m and right edge line is at 3,5m.

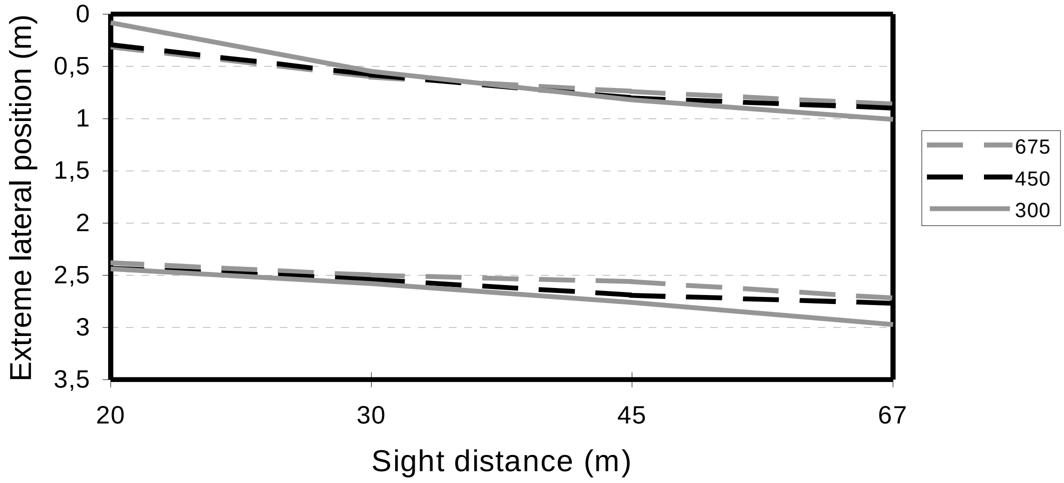


Figure 6.20 - Extreme lateral position of the wheels in right curve without clothoid at 90 km/h.

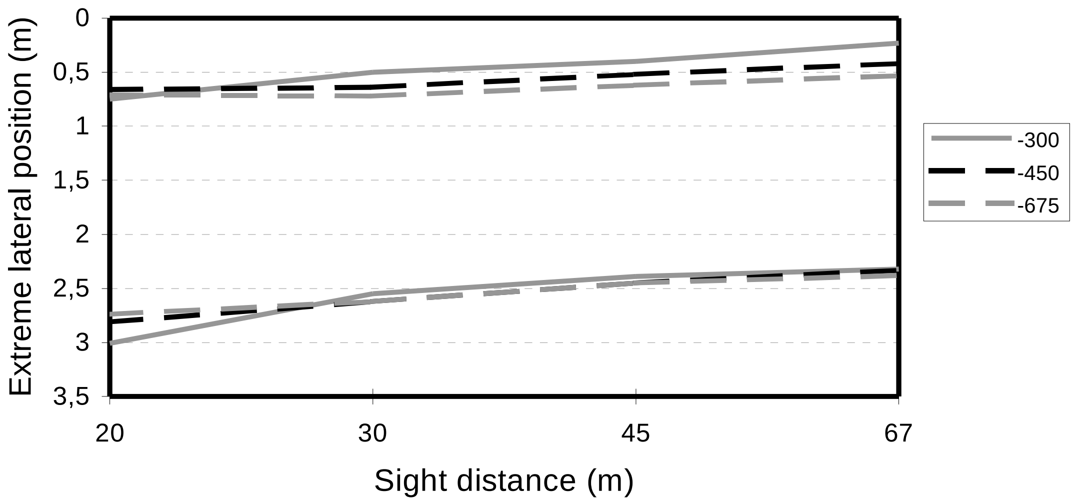


Figure 6.21 - Extreme lateral position of the wheels in left curve without clothoid at 90 km/h.

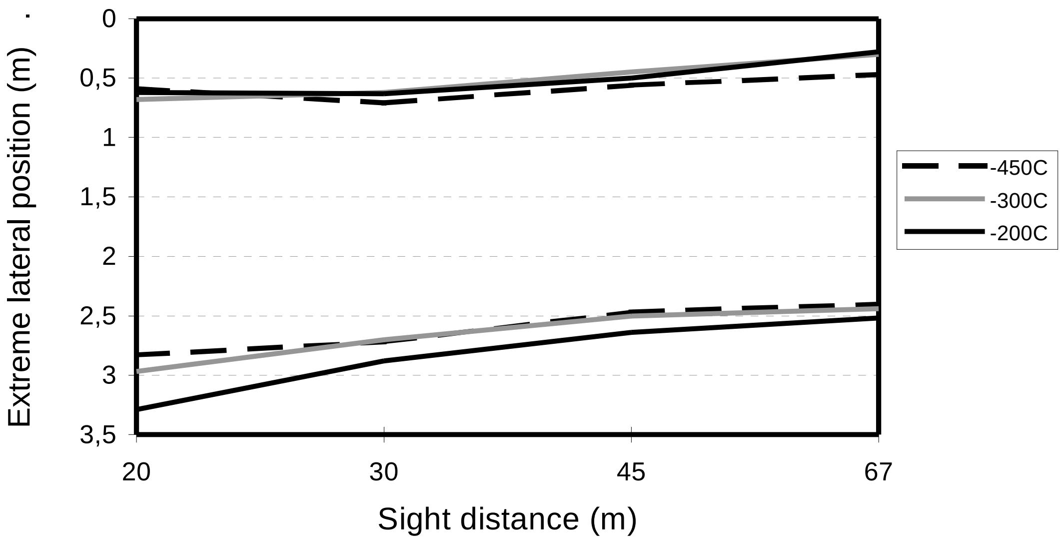


Figure 6.22 - Extreme lateral position of the wheels in right curve with clothoid at 90 km/h.

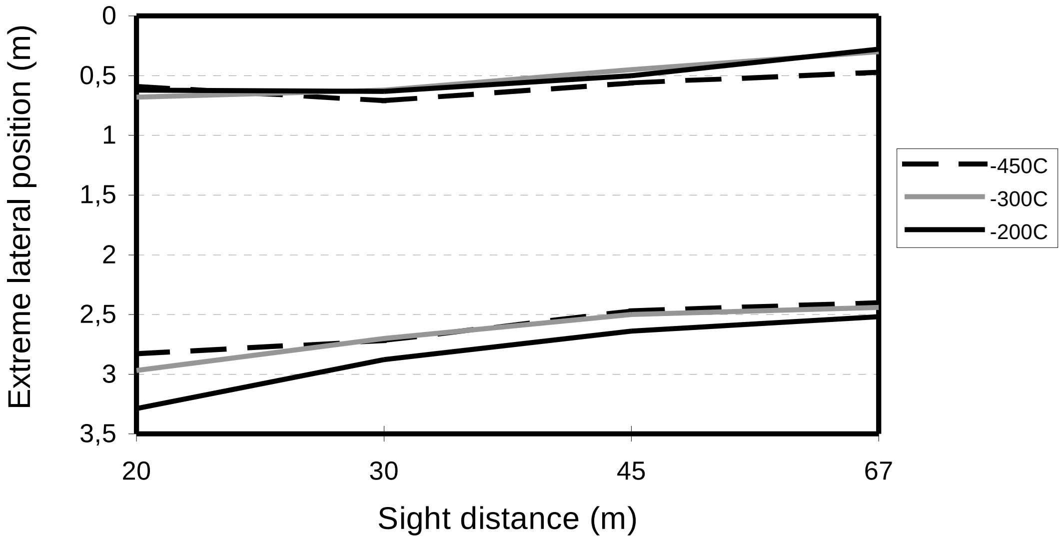


Figure 6.23 - Extreme lateral position of the wheels in left curve with clothoid at 90 km/h.

The *extreme lateral position* of the outer wheel is further out in a curve with *clothoids* ($F(1;353) = 13,0$; $p<0,001$ for right and $F(1; 353) = 6,9$; $p<0,001$ for left curve). There is no significant interaction with *sight distance*.

All results from Analysis of Variance for extreme lateral position at 90 km/h are included in table 6.9. The effect that sight distance (s), radius (r) or the interaction (s x r) have on the extreme lateral position is tested. The boxes for the outside wheel in the curve are tinted. Only effects significant at the 0,05 level are included.

Table 6.9 - Analysis of Variance for extreme lateral position at 90 km/h

Clothoid	Curve	Wheel	df1	df2	Affect	F	p<
no	right	left	3	349	s	159,0	0,001
			6	349	s x r	4,6	0,001
no	right	right	3	349	s	48,0	0,001
			2	349	r	13,5	0,001
no	left	left	3	349	s	29,2	0,001
			2	349	r	17,7	0,001
			6	349	s x r	3,2	0,01
no	left	right	3	349	s	67,5	0,001
			6	349	s x r	3,6	0,005
yes	right	left	3	349	s	151,8	0,001
			2	349	r	17,4	0,001
			6	349	s x r	4,9	0,001
yes	right	right	3	349	s	55,7	0,001
yes	left	left	3	349	s	25,3	0,001
yes	left	right	3	349	s	73,9	0,001
			2	349	r	26,6	0,001
			6	349	s x r	2,9	0,01

6.3.5 Standard deviation of lateral position

Standard deviation of lateral position gives information about cutting curves or "missing" curves as well as "staggering". The average of the standard deviation of lateral position (group mean values) for the 24 subjects at both speed conditions, is shown in figure 6.24. By using the average, the standard deviation between subjects is excluded.

The standard deviation at the condition free choice of speed is larger at longer sight distances. This might be caused by cutting of curves. At the condition 90 km/h the standard deviation is higher at both very short and very long sight distances. In between it is lower. The higher values at longer sight distances might be because the driver is cutting curves and the higher values at shorter sight distance might be because of both "staggering" and "missing" of curves.

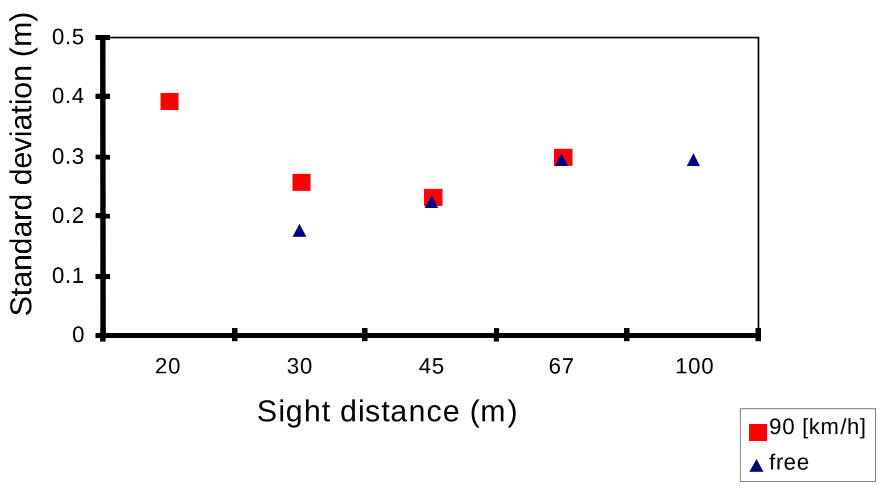


Figure 6.24 - Standard deviation of lateral position at both speed conditions.

6.3.6 Distance outside road marking

This measure identifies for how long a distance either the right or the left wheel pair have been outside either road marking. The results show that the driver drives outside the road markings to a larger extent when the speed is set to 90 km/h than at own choice of speed. The average distance on, or outside, road markings (group of mean values) for the 24 subjects at free choice of speed and at the condition of 90 km/h is shown in figures 6.25 and 6.26 respectively. It can also be seen that the car is driven for a longer distance outside the centre line than outside the edge line.

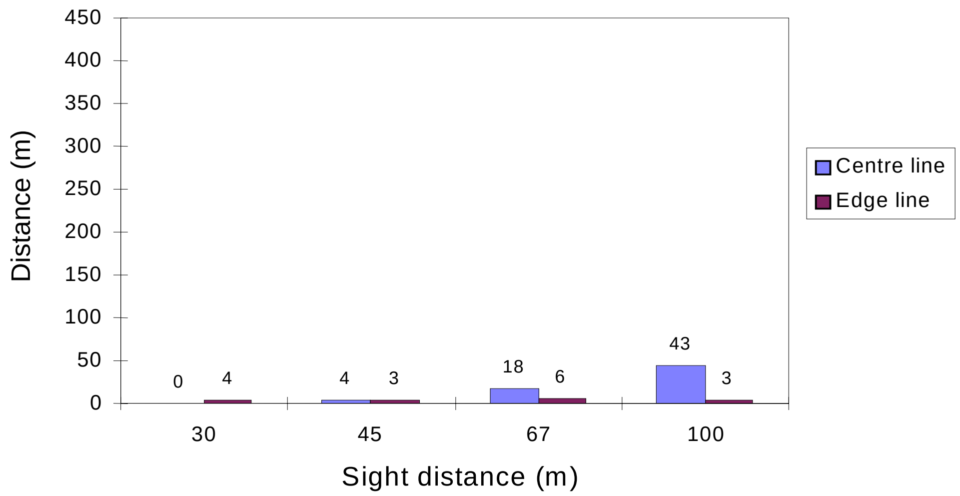


Figure 6.25 - Distance driven on, or outside, road marking at own choice of speed.

At free choice of speed the distance driven outside the centre line increases for longer sight distances. This might be because drivers are cutting the curves or allowing themselves to "stagger". At 90 km/h the distance is larger at short sight distances. This is true for both centre and edge lines. This might be because the driver is "missing" the curve or "staggering". The distance outside the line is also longer at 67 than at 45 m. This might be because the driver is cutting the curves or allowing himself to "stagger", just as for the longer sight distances at the condition free choice of speed.

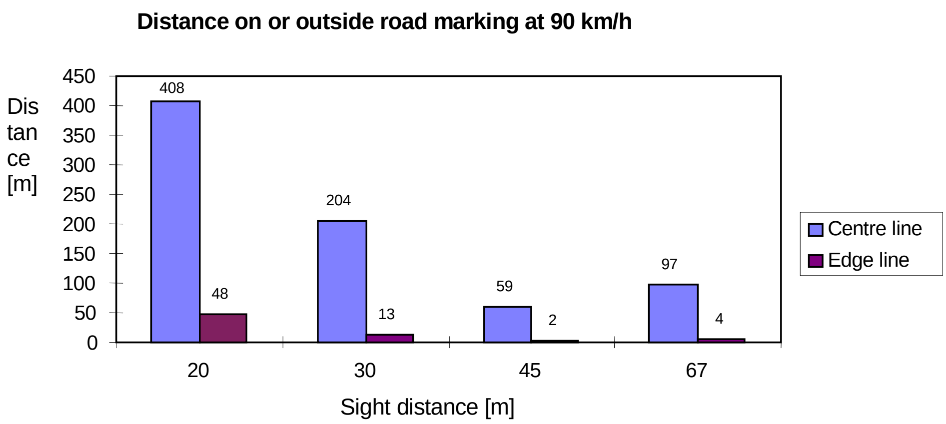


Figure 6.26 - Distance driven on, or outside, road marking at 90 km/h

6.4 Conclusions

This study was carried out to investigate the extent of the driver's need for visibility of road markings when relying upon the vehicle's lighting system. The need for visibility was defined in the following way: **"the shortest visibility distance or limit of road marking that the driver needs in order to handle the car in a safe and controlled way."** The purpose of this study is not to find the level of visibility that is most comfortable for driving nor to find the safest level of visibility of road marking. Drivers' need for visibility of the road at night has been studied when the driving task is to keep the car in the driving lane.

It is very important to be aware that the data collected in the simulator study are not to be directly generalised to real driving situations. Even though the simulator is advanced, it is not a perfect copy of real driving. Data should therefore be used with caution. But, as discussed in the introduction, this study would have been very difficult if not impossible to carry out as a full-scale experiment on a road or a test track.

Another relevant point to be considered is the design of the experiment, with the two test conditions and their validity and what information they supply. The condition free choice of speed is of course closest to real driving. But the result from this condition doesn't give much information regarding drivers' need for visibility. **However, it shows that drivers are very good at compensating for poor visibility conditions by lowering speed and reducing their variation in lateral position in the driving lane.** Drivers act in this way in order to keep control. The other condition, driving with cruise control set at 90 km/h, is an unrealistic situation but it exposes the limits of driver performance much better. This driving situation is not totally unrealistic, because there is evidence that drivers often do not reduce their speed enough in poor visibility conditions, but maintain too high a speed. This may be because of the speed limit or their habit of driving at a certain speed on a specific road. The two experimental conditions expose different aspects of the driver's need for visibility of the road marking ahead. Combined, they give valuable insights into how good sight conditions have to be for the driver to manage the driving task without problems. Any conclusion about safe visibility conditions for detection of unexpected obstacles on the road surface cannot be made from these results.

From the results obtained in the driving simulator, the following conclusions can be identified about the driver's needs of preview time:

- When studying **level of speed** at the condition free choice of speed, we assume that the driver reduces speed for shorter sight distances to compensate for the more difficult conditions. The results show that the driver does not find it more difficult to drive with 67 m sight distance than with 100 m, because there is no difference in choice of speed. Somewhere between 67 m and 45 m the sight distance starts to affect the driver's choice of speed. From this it can be concluded that the visibility of road markings on the test route does not need to be greater than 67 m.

- It can be seen from **speed and the speed difference per radius** that the driver reduces speed more at longer sight distances than at short sight distances when approaching a curve with a small radius. At shorter sight distances the driver in general keeps to a lower speed because the preview time to the start of the curve is shorter and that forces him to do so. This result shows that the driver is good at compensating for poor visibility by choosing a lower speed.

- The **lateral position** at the condition free choice of speed shows clearly how the subjects, by adjusting speed, stay in control of the situation and do not "miss" the curves. At the condition 90 km/h it can be seen that the subject starts "missing" the curves at sight distances shorter than somewhere between 30 and 45 m. The lateral position shows that the driver can handle the car when the sight distance is 45 m. It should be noted that this result only is valid for 90 km/h.

- The **extreme lateral position** of the wheels at the condition free choice of speed gives the same information as the lateral position. The result shows that the driver is good at adjusting the speed to the sight conditions so the car does not move towards the outer edge of the driving lane in the curves.

  In the cruise control condition the extreme lateral position of the car in a curve moves toward the outer edge of the driving lane at short sight distances. At a sight distance of 45 m the car moves toward the inner edge of the driving lane in the curve, but at 30 m sight distance the car moves toward the outer edge. If the extreme lateral positions for right and left curves are compared it can be seen that they cross. This could be a sign that at sight distances lower then the point where the curves in the graph cross the visibility of road markings is below what the driver needs. This happens at a sight distance somewhere between 45 and 30 m. Exactly where depends on the characteristics of the radius of the curve.

- **Standard deviation** of the lateral position at free choice of speed shows that the driver does not have any problems with "staggering" or "missing" the curve when the sight distance decreases. The driver decreases speed when the sight distance is shorter and at the same time the variation in lateral position decreases. This shows that drivers are good at adjusting speed and lateral position to compensate for bad sight conditions.

  At the condition 90 km/h the standard deviation seems to have a minimum somewhere between 30 and 45 m sight distance. The increased standard deviation at longer sight distances than this minimum is probably caused by cutting curves or "staggering" that the driver allows himself because he experiences a large safety margin. The increase of standard deviation at shorter sight distances than the minimum is probably caused by "missing" curves and increased "staggering" and is a sign of the driver’s loss of control. These results show that down to the sight distance 45 m the driver has full control at 90 km/h.

- The **distance driven outside road marking** gives similar conclusions to the standard deviation of lateral position. The driver seems to be cutting curves to a larger extent at longer sight distances at the condition free choice of speed. At the condition 90 km/h there is probably a minimum in distance driven outside the road marking close to 45 m sight distance. This is the case both for centre and edge lines. Distance outside the road marking therefore also indicates that the driver is able to handle a sight distance of 45 m at 90 km/h.

  A sight distance of 45 m at 90 km/h means 1,8 s of **preview time**. The preview time at the condition free choice of speed becomes shorter with shorter sight distances but is never less than 1,8 s. It is not possible to judge whether the chosen preview time would have been shorter or the same at 20 m sight distance at the condition free choice of speed, but it is clear that drivers choose preview times as short as 1,8 s and still handle the driving task well.

- When setting the **lower limit for visibility** of the road marking ahead, the safety aspect is important. The results show not one lower limit, rather a range of sight distances that varies for every driver and situation. The results of this experiment indicate that a safe limit of visibility of road marking for the driver to keep the car in the driving lane is somewhere in the interval 30 - 45 m when driving at a speed of 90 km/h. If one single figure must be chosen the choice should be 45 m. This corresponds to a preview time of 1,8 seconds. Preview time should be used as the measure because this measure is independent of driving speed (e.g. when driving at a speed of 120 km/h a preview time of 1,8 s gives a safe preview distance of 60 m).

  Figures 5.1 – 5.3 in chapter 5 show visibility distances related to time pattern and retroreflectivity for edge lines and centre lines in high beam and low beam illumination.

  The driver's preview time of 1,8 seconds to the visibility limit of road marking ahead should be regarded as the more general measure. It must though be kept in mind that this is an absolute minimum limit for safe driving. In real driving the driver now and then also must have time to check the rear view mirrors and the instruments on the dashboard. For this reason a short time period should be added to the preview time of 1,8 s. The size of this time period needs a literature review or further research. An additional allowance will also be needed for unexpected incidents, as well as a margin for comfort.

Chapter 7. Driver behaviour

7.1 Introduction

The basic objective of this part of the research was to determine and quantify the effects of various types of longitudinal road markings on driver behaviour. Since the scope of the task does not permit directly focusing on accidents, implications for road safety are made on the basis of driver behaviour.

The study conducted was a field experiment carried out in real traffic conditions for observing driver behaviour. An unobtrusive instrumented car, developed by VTT (Technical Research Centre of Finland) was used in the study (see figure 7.1). A Differential-GPS (Global Positioning System) and special software were used for measuring the precise lateral position of the test car. The observations were made by measuring variables describing driver behaviour such as **speed** and the **lateral position** of the car on the road (described by the 99th percentile values of the lateral positioning distribution relative to the edge lines). Finally, **visibility distances** and **preview times** were calculated for the test roads based on speed and road marking performance parameter results. Large-scale field studies with accident data are needed to make a reliable assessment of the safety effects of different types of road markings.

Figure 7.1 - Unobtrusive instrumented car

The following factors were taken into account when the experiment was planned:

- generalisation value of the results across European driver populations;
- generalisation value across different road conditions;
- minimisation of error variance caused by measurements in real traffic;
- approaching or simulation of conditions where road markings are especially needed;
- data allowing robust statistical treatment (inclusion of control conditions);
- measurements having as little impact on driver behaviour as possible.

The tests were carried out in three different countries making a cross section of Europe (see table 7.1).

Table 7.1 - Design of the experiment

Country	Area	Total length (km)	General description
Finland	Orimattila	61	Long curvy and straight stretches
Portugal	Troia	36	Mainly straight stretches, narrow
Switzerland	Neuchatel	30	Mainly curvy stretches, narrow

It was agreed to apply four different combinations of road markings (including continuous and broken lines) trying to repeat their design and brightness in the three test locations.

The experiment made it possible to draw interesting conclusions from the behaviour of drivers as a function of introducing different types of road markings.

7.2 Methodology

The unobtrusive instrumented car developed by VTT was used for measuring driver behaviour. The subjects drove the car twice on the same road: first without road markings and the second time when there were different types of road markings painted on the road.

Since the tests comprised two consecutive driving periods with two to three weeks interval, it was reasonable to assume that driving conditions other than those related to the road markings (e.g. weather, driver state etc) might affect results. For this reason, some test road stretches were kept constant, unchanged throughout the tests (control sections). The assumption underlying this rationale is that, in case there are factors other than road markings which may account for changes in driver behaviour, they are manifest also on these unchanged road stretches and their effects can be quantified and separated from the effects of road markings in the statistical treatment of the data.

Accordingly, the general design of the experiment can be depicted as follows (Table 7.2).

Table 7.2 - Design of the tests.

BEFORE Test sections before, the first driving period	**X**	**X**	**X**	**X**	**X**	**X**
AFTER Test sections after, the second driving period	**A**	**X**	**B**	**C**	**X**	**D**
X = Test section with no markings, or with existing worn road markings A,B,C,D = Test section with new road markings (applied according to the design criteria)						

It should be pointed out that while the inclusion of control stretches in the design may eliminate some problems associated with different conditions - whether associated with drivers or road environment- it does not solve all the problems caused by the possibly changed conditions. This may be the case e.g. with a wet road surface. The interaction of wetness and road marking qualities may be different in the control stretches than in the stretches with road markings, for the simple reason that control stretches do not have road markings. So there will always be error variance caused by different driving periods in field tests that cannot be totally explained by the inclusion of control stretches.

7.2.1 Test roads

The tests were carried out in three different countries making a cross section of Europe: Finland, Portugal and Switzerland (see table 7.1).

For the analysis the test road was split into curvy and straight sections. The straight sections were merged into one analysis section. The curvy sections were split again into left-hand and right-hand bends. Especially in terms of the number and type of curves, the test roads were different, as can be seen in the tables 7.1 and 7.3.

A data programme was developed for defining a curve. In this data a road section having either a right-hand or a left-hand bend with an angle exceeding 7 degrees was defined as a curve. Road sections having a bend less than 7 degrees were defined as straight sections.

The test roads were rather different in terms of curve parameters. Finland had the sharpest curves, whereas the curves in Portugal and Switzerland were equal in terms of the curve angle and the standard deviation of the angle. Portugal differed from the other countries in having a remarkably straight test road.

Curve radius parameters give additional information about the test road in the three countries (see table 7.3). The curves were longest in Portugal, exceeding the average length of the curves in Finland by more than 200 metres and in Switzerland by more than 300 metres. The curves were shortest in Switzerland measured by the mean, maximum and minimum radius lengths.

Table 7.3 - Curves of the test roads by radius-parameters.

Radius-parameter	Finland	Portugal	Switzerland
Mean, metres	458	673	358
Minimum, metres	102	295	83
Maximum, metres	2 214	1 091	1 162
Standard deviation, metres	339	330	267
Number of curves	126	30	65

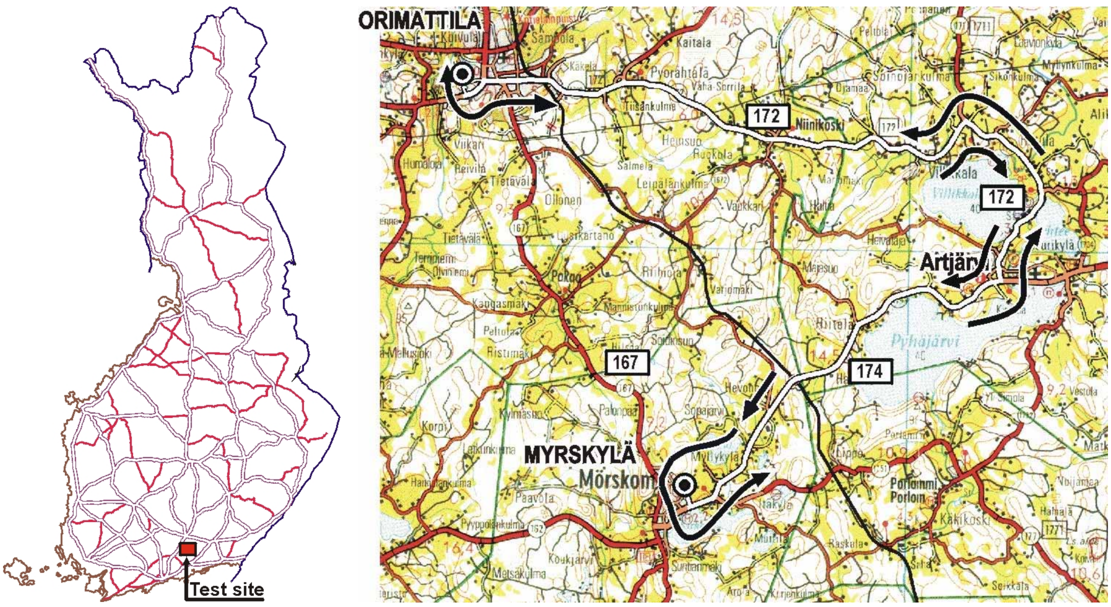


Figure 7.2 - Finnish test road

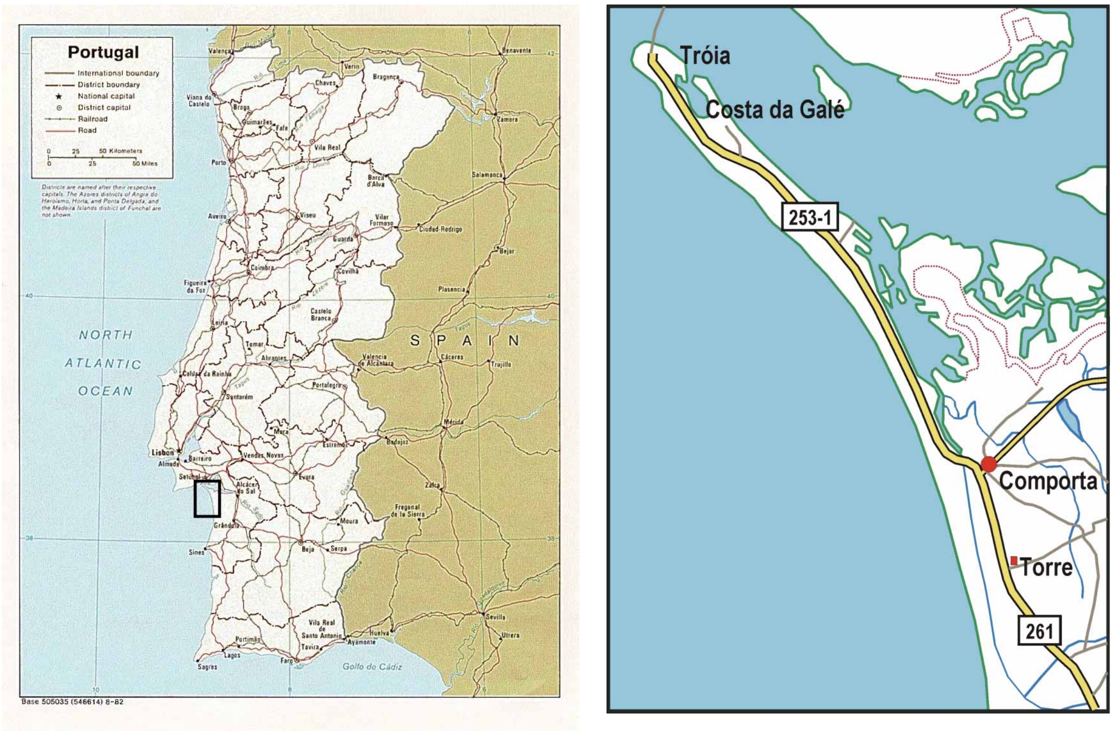


Figure 7.3 - Portuguese test road

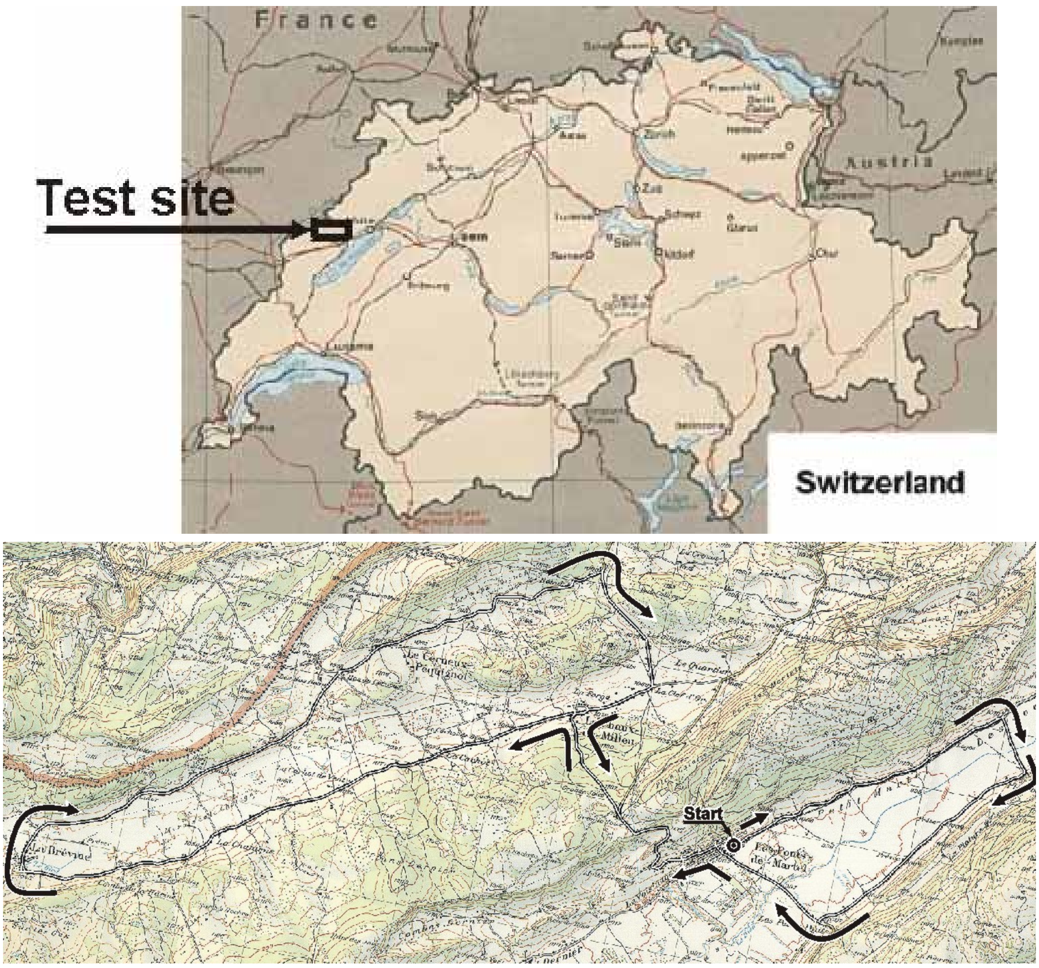


Figure 7.4 - Swiss test road

7.2.2 Road markings

Road markings selected for the trials were a result of a compromise based on the previous results obtained in the development of the Action COST 331. It was agreed to use four different road marking types that were to be identical in each three countries (see table 7.4). In Portugal, for technical reasons the target widths of road markings were not quite achieved. Moreover, the target values for the luminance coefficient for retroreflection (R_L/mcd·m^{-2}·lx^{-1}) were not achieved in all test sections in the three countries, partly due to difficulties in adjusting the right amount of drop-on glass beads and partly due to the unexpected traffic conditions on the test road (Finland). In Finland the overall retroreflection level remained low, which means that high target retroreflection values of 300 mcd·m^{-2}·lx^{-1} were not reached. However, differences in retroreflection levels in terms of different edge markings remained in most cases (even though at some points the differences could have been greater).

In addition to these four road-marking types, three other line types were used in Finland. These were two types of edge lines without centre lines and one centre line type without an edge line. The analysis of the results deals with the four road marking types used in all the three countries.

In Finland and Portugal the test roads were driven back and forth doubling the number of analysis sections. The test routes were circular in Switzerland and were driven once making up 9 different analysis sections.

Table 7.4 - Description of the test sections

Line type (Design of the line, width and target value for retroreflection)	**FIN**		**P***		**CH**	
	Number of test sections	Effective R_L/mcd·m^{-2}·lx^{-1}	Number of test sections	Effective R_L/mcd·m^{-2}·lx^{-1}	Number of test sections	Effective R_L/mcd·m^{-2}·lx^{-1}
Continuous 10 cm/100 mcd/m²/lux	2	67	2	117	1	220
Continuous 10 cm /300 mcd/m²/lux	2	117	2	377	1	201
Continuous 30 cm/100 mcd/m²/lux	2	97	2	209	2	118
Broken 10 cm/300 mcd/m²/lux	2	79	2	322	3	262
Continuous 10 cm/100 mcd/m²/lux edge only	2	56	-	-	-	-
Continuous 10/300 mcd/m²/lux edge only	2	97	-	-	-	-
Centre line only 10 cm /300 mcd/m²/lux	2	< 60	-	-	-	-
Control, existing (worn) road markings	2	**)	2	85	2	**)
Total number of test sections	16		10		9	

***)** In Portugal 12 cm wide edge and centre lines instead of 10 cm lines and 24 cm wide edge lines instead of 30 cm wide edge lines were used. **) For the calculation of preview-times, the values of 35 mcd·m^{-2}·lx^{-1} were used.

A special measuring car (ECODYN), constructed for measuring the luminance coefficient of retroreflection, was used in Finland and Portugal. The ECODYN is a high-speed measuring apparatus used in normal traffic producing in a single driving pass:

- luminance coefficient for retroreflection (according to the measuring geometry specified in the European standard: EN 1436),
- day contrast,
- night contrast and

- diagrams of variations of retroreflection coefficient.

In Switzerland the measurements were carried out by using manual retroreflection measuring equipment.

7.2.3 Subjects

Normal drivers having a driver's licence were recruited for the tests. This was done to maintain the generalisation of results in terms of the greatest part of the driver population. The age of the subjects ranged from 25 to 60. For safety reasons the extreme ends of the driver population were excluded from the tests. The drivers were recruited in a way that eliminated selection bias as far as possible. However, the sample was biased in Portugal including mainly male subjects (83 %). In the other two countries the sex distribution was roughly the same as in the car driving population. The mean age of the subjects in Finland, Portugal and Switzerland was 41, 36 and 34 years respectively.

7.2.4 Instruction and tests

The subjects were given instructions with essentially the same content in each country. They were told that the objective of driving the route was to obtain their opinions and experiences concerning night time driving. The subjects would drive the test route twice in night time conditions. They were also asked to fill in an interview questionnaire after each test-drive. The subjects were then shown the test route on a map, and the controls of the car. They were asked to drive along the test route in the manner in which they usually drive, and if they should lose their way, they were asked to try to get back on the route by the shortest route. After the test-drives the subjects were told that data from their drives were stored on a computer and on video tape, and their permission was asked for using the registered data for analyses. All the subjects agreed.

The experiment was carried out with an instrumented vehicle capable of recording a great number of variables describing driver behaviour (see e.g. Rathmayer & Mäkinen 1995). The instrumented vehicle used for this study was equipped with a forward-looking video camera and several transducers conveying information about driver behaviour. The data was stored on a computer in the boot of the car. All instrumentation was hidden in the car. The driving of the whole test route was recorded. For practical reasons, the analysis of the data was limited to pre-selected test sections, which made up a representative sample of the route.

Unobtrusiveness meant here that the instruments/transducers were hidden, and the subjects were not aware of their presence (see figure 7.1). Moreover, it meant that the exact purpose of the task was not revealed to the subjects until after the test-drives. The instruction was given in a way that approximated the truth, but was not the whole truth. This applied especially to measuring driver behaviour. The subjects were told that they would be interviewed after the drives to chart their opinions and experiences concerning night time driving with the implication that this would be the only monitoring carried out.

The only exception to the rule of unobtrusiveness was the GPS antenna in the ski-box on the roof of the instrumented car. The subjects were told about the antenna in the box. The interior of the car, however, was totally standard without any visible measurement instrumentation.

For this experiment the car was equipped with transducers for measuring:

- speed: error (reliability when repeating measurements) in speed measurements not exceeding 0,2 km/h;
- lateral position: describing the position of the outer edge of the right tyre of the test car expressed in centimetres; 0-value indicating that the outer edge of the test car is in the middle of the road marking, negative (-) value indicating the crossing of the edgeline centre and positive (+) values indicating a shift towards the centre of the road; error in the lateral position measurements was +/- 2,0 cm (only data within this error margin were included in the analysis);
- lateral acceleration: expressed in g and varying in this experiment between 0,0 – 1,0 g ($g = 9{,}81\ m/s^2$);
- longitudinal acceleration: expressed in g (data was not fully analysed, only screening of the data carried out);
- use of brakes: intensity 0 - 100 Bar, proportion (%) of driving time brakes used (data was not fully analysed, only screening of the data carried out);
- use of steering wheel: angle 1 - 360 degrees (data was not fully analysed, only screening of the data carried out);
- use of lights (head, dipped): mainly headlights used in the experiment and due to the small proportion of the dipped lights used in the tests, the effects of this were not considered);
- a forward-looking video camera: for recording the scene ahead mounted in the extra brake-light box on the rear window of the car (the video image was used for checking the data when needed).

The Global Positioning System (GPS) equipment consisted of a dual-frequency kinematic receiver and antenna in the car linked with the on-board computer so that the computer time was the same as the GPS time (GMT).

The base station had a similar GPS-unit with the antenna at a fixed location. The GPS equipment was obtained from and operated by the Finnish National Road Administration (Finnra). The GPS unit in the car was controlled at the base station using a radio modem. The GPS position accuracy of the equipment is ±2 centimetres at best. This accuracy in measuring the lateral position of the instrumented car was achieved partly by using a separate portable base station which was mounted on conspicuous places such as on the roofs of buildings along the test routes. The position of the car was registered every second so that when for example the car was travelling at 80 km/h the position was registered at about every 22 metres.

The tests were carried out at night. At first, the subjects were taken inside the base station, shown the map of the test route and given some general information about the tests. During this time the equipment in the car was prepared for the test out of sight. The subject was then taken to the car and shown the controls. After this, the subject drove the test route. The first 10 - 15 minutes of the drive was not included in the analysis to allow the subjects to get used to the car.

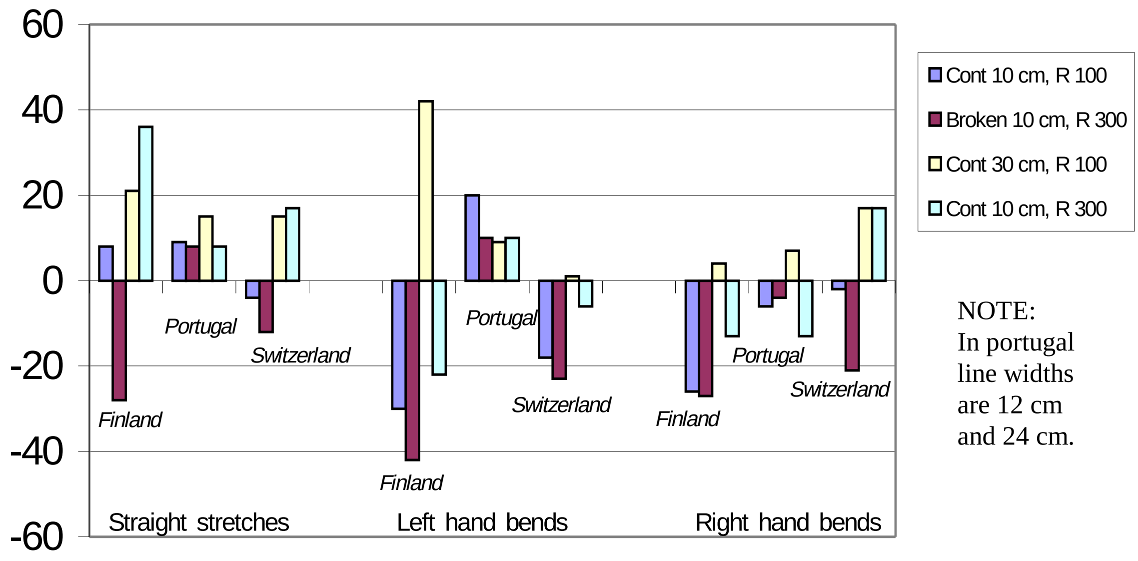
After the test drive, the driver was again taken inside the base station and handed a questionnaire to fill in. The equipment in the car was not shown to the drivers at any stage of the tests.

7.3 Results

7.3.1 Lateral position

Lateral positioning of the test car was measured as a distance (cm) from the centre of edge lines, since this was assumed to be more critical in terms of safety than the distance from the centre line. The extreme positioning closest to the edge of the road is regarded as one of the most interesting variables in this study. This positioning was described by the 99th percentile values of the lateral positioning distribution (i.e. the values closest to the centre of the edge line that are exceeded by only 1 % of the values in the lateral positioning distribution).

Figure 7.5 describes the change in the 99th percentile lateral position values after compensating for the change in the control stretches. Positive values indicate a change in the lateral position towards the centre of a road and the negative values a change towards the edge of the road.



NOTE:
In portugal line widths are 12 cm and 24 cm.

Figure 7.5 - 99th percentile values of the change in the lateral position (cm) by road marking type.

First, it can be seen that in the straight stretches there was generally a trend towards the centre of the road in the lateral position of the test car. The change was greatest in terms of the widest (24 cm and 30 cm) edge lines. The exception was the broken edge line in Finland and in Switzerland, with a tendency to push the test car towards the road edge.

When considering left-hand bends, it can again be seen that the widest edge lines seem to push the car towards the centre of the road, whereas broken edge lines have – disregarding Portugal – the opposite tendency.

The above observations apply also to right-hand bends. In all three countries there was a shift towards the centre in terms of the wide edge markings and a shift towards the edge in terms of the broken edge lines.

The change in the lateral position of the test car was not associated with either changes in the preview time or with changes in visibility distance (Pearson correlation coefficients

0,16 and 0,23, respectively). It seems rather that the mere existence of the lines serves as a reference for the positioning of the car on the road, and how far the lines can be seen may not be relevant in this context. The effects of the wide lines can be simply explained by the fact that if drivers want to avoid driving on the line or crossing it, they have to steer the car somewhat more to the centre than is the case with normal 10 cm lines.

It should also be pointed out that drivers did not like broken edge lines. Despite the slight speed increase suppressing effects of about 1 km/h of broken edge lines at some points, their negative effects seem to be greater than their positive effects.

Finally, it is also possible that the effects of the road markings on the lateral positioning of the car are also associated with the type of curve and also with the length of the straight stretches both preceding and following the curve.

There are a number of factors that may explain the effects of road markings on the extreme lateral positioning of the test car that could not be controlled in this study. These are as follows:

- type of curve (horizontal and vertical): radius varied by country;
- width of the road: also varied by country;
- weather conditions: were different in Finland after painting the road markings;
- different before-conditions: there were old, worn-out road markings with some retroreflectivity left in Finland and Portugal, but no markings in Switzerland.

Generally, the results indicate that drivers are very good at using all information from the road environment - not only the information provided by road markings. The changes in terms of speed and lateral position are so small compared to the before-conditions with very poor or no road markings that other information must have a substantial role in driving. The effects of the information from the rest of the road environment are almost impossible to control.

7.3.2 Travel speed and preview time

Travel speed data does not at first sight give a lot of information on the effects of road markings. Figure 7.6 describes the change in the mean travel speed by road marking type after compensating for the change in the control stretches. Results from the Finnish test road indicate a generally slight speed decrease, whereas the opposite seems to be the case with Portugal and Switzerland. In fact, there is a rather large speed increase seen in Switzerland.

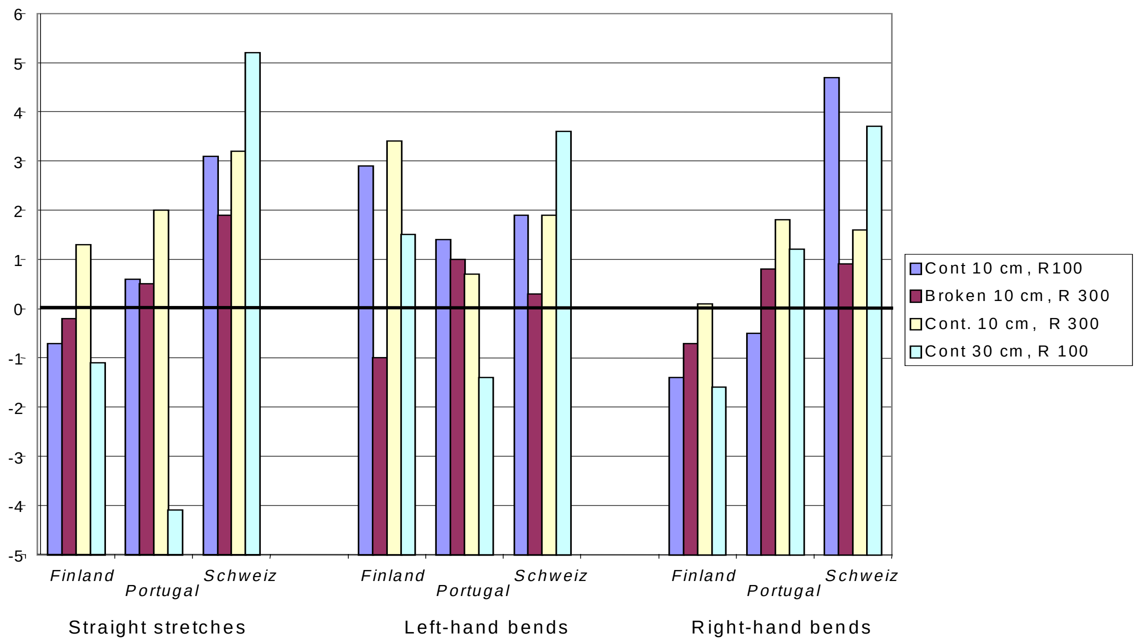


Figure 7.6 - Change in the mean travel speed by road marking type.

The **effective road marking area** multiplied by the coefficient for retroreflection (R_L) is the same in terms of both the continuous 10 cm wide line with a coefficient of retroreflection of 100 $mcd{\cdot}m^{-2}{\cdot}lx^{-1}$ and the broken edge line with a coefficient of retroreflection of 300 $mcd{\cdot}m^{-2}{\cdot}lx^{-1}$. Also the road marking types with a width of 10 cm and a coefficient of retroreflection of 300 $mcd{\cdot}m^{-2}{\cdot}lx^{-1}$ and a 30 cm wide marking with a coefficient of retroreflection of 100 $mcd{\cdot}m^{-2}{\cdot}lx^{-1}$ are identical when using the above criterion. Based on this, it would be reasonable to assume that the two left-hand side columns would have the same speed effects, and likewise the two right-hand side columns would have the same speed effects. However, this was not the case.

In addition to the differences in the test stretches, the differences in speed levels could be explained by the fact that the target level of retroreflection was not reached in the three countries. Moreover, in Portugal the effective widths of the lines were 12 cm and 24 cm and not 10 cm and 30 cm as in the other two countries. Finally, the countries differed also in terms of the control situation, when Finland and Portugal had worn-out road markings with some retroreflection left (about 50 $mcd{\cdot}m^{-2}{\cdot}lx^{-1}$ and 85 $mcd{\cdot}m^{-2}{\cdot}lx^{-1}$, respectively), whereas there were no lines before painting the test markings in Switzerland.

There are also other factors relevant for the speed choice that could not be controlled in the study of the three countries, such as:

- lane width: was different in the test countries;
- road surface qualities probably varied: there was also more driving in rain in Finland during the second test period than in the other countries;
- vertical radius: has a great effect on visibility distances, and this parameter varied by type of test stretch within a country and between the countries;
- also horizontal radius and the length of straight stretches varied: the straightest roads were found in Portugal;
- vegetation and other road environment related factors: relevant for the optical guidance also varied between countries. There was, however, no systematic use of delineators or

roadside posts in any of the test areas which would account for the differences in results.

The real conditions before and after the painting of road markings on the test roads are presented in table 7.5. "Test stretch" indicates the type of road marking used after painting and the target retroreflection value (R_L/mcd·m^{-2}·lx^{-1}). Before painting the road markings, there were 10 cm wide edge lines in Finland and 12 cm wide edge lines in Portugal and none in Switzerland. This applies also to the control stretches. "Effective" means the measured retroreflection values. "Visibility (m)" indicates the visibility distance in metres after painting the road markings and ΔS indicates the change in the visibility distance after painting the road markings. Moreover, the visibility distance calculations are based on the assumptions of "medium/difficult conditions" as described in Annex D.

Table 7.5 - Test stretches after the introduction of road markings.

Test stretch	**Country**	**Width (cm)**	**Efffective R_L (mcd/m^2/lux)**	**Visibility (m)**	**ΔS (m)**
1	FIN	10	67	53	+ 7
Continuous	P	12	117	68	+ 8
R_L =100	CH	10	220	79	+38
2	FIN	10	79	45	- 1
Broken	P	12	322	73	+13
R_L =300	CH	10	262	67	+26
3	FIN	10	97	61	+15
Continuous	P	12	377	90	+30
R_L =300	CH	10	201	77	+36
4	FIN	30	97	74	+28
Continuous	P	24	209	90	+30
R_L =100	CH	30	118	79	+38
	FIN	10	50	46	-
Control	P	12	85	60	-
	CH	-	-	41*)	-

*) The same preview time assumed in Switzerland as in Finland and Portugal

It can be seen from table 7.5 that applying new markings in the stretches 1 and 2 did not cause great changes in terms of visibility in Finland and in Portugal. When looking at figure 7.6, this is reflected in the fact that there are no great changes in travel speed levels in Finland and Portugal. The exception to this are the left-hand bends in Finland where the speed increase was – taking into account the speed change in the control stretches – almost 3 km/h after the road markings were painted. It could be pointed out, however, that the speed increase was relative rather than absolute, since the speed level dropped in the control stretches by 3,6 km/h during the second drive.

In the stretches 3 and 4 (Table 7.5) the increase in the visibility distance in Finland and Portugal was 15 and 28 metres respectively. According to figure 7.6, this contributed to a slight speed increase in these countries.

However, in Switzerland the increase in visibility was more substantial (from about 25 to 40 metres) than in Finland and in Portugal. This was also followed by a clearly greater speed increase, ranging roughly from 2 km/h to 5 km/h.

Generally, when looking at the association between the mean travel speed change and the change in visibility – including the compensation in the control stretches (= the effect of before/after-change), there is a statistically significant ($p < 0.05$) correlation in terms of the straight stretches, the left-hand and the right-hand bends. This means that when the visibility increases, the mean travel speed level also increases.

When investigating the speed change and the change in the visibility of all road markings with different types of test stretches combined (straight, left right), the following regression line can be presented (see figure 7.7). That regression line is represented with the 95 % confidence interval.

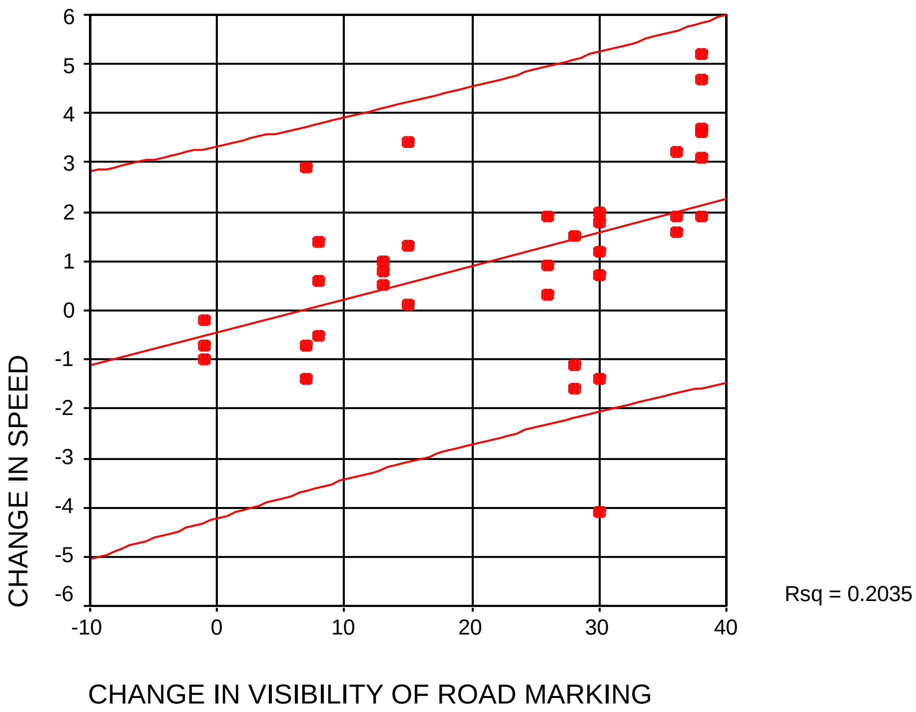


Figure 7.7 - Relationship between the change in the visibility of road markings and the change in the mean travel speed level.

From figure 7.7, the following equation can be deduced for the regression line obtained (correlation coefficient, r = 0,45):

$$\Delta v = -0{,}4 + 0{,}068 \times \Delta S \qquad \textit{(Equation 10)}$$

The positive correlation is statistically significant, but the correlation is still so weak that its predictive power is low. Statistically significant speed increase is not reached until the visibility distance has increased by about 70 metres. However, the speed increase most probably starts when the increase in visibility has exceeded 6–7 metres (see figure 7.7). Moreover, it can be seen from the regression line that the speed increase does not exceed 1 km/h unless visibility increases by more than 20 metres. For the mean travel speed increase to exceed 2 km/h, a visibility increase of more than 35 metres is needed. This was the case mainly in Switzerland.

A considerable part of the mean travel speed increase expressed by the regression line in figure 7.7 can be explained by the results from the Swiss test road, where the increase in speed level was considerable, apparently a consequence of substantial increase in the visibility distance. In this experiment, repainting caused an increase in visibility distances of 30 metres at most, and this was achieved only once with the increase of R_L of about

290 mcd·m^{-2}·lx^{-1}. Usually, one could expect repainting to produce an increase in R_L of about 200−250 mcd·m^{-2}·lx^{-1} at most. Moreover, this situation occurs only when the road markings are new.

Other influences of road markings in drivers' behaviour may be also assessed through the analysis of the changes in preview times (see table 7.6). Therefore, table 7.6 shows the preview times before and after the painting of road markings. In the table, Δt describes the change in preview time after the painting of road markings. The test roads in Finland and in Portugal had continuous edge lines 10 cm and 12 cm wide respectively, whereas there were no edge lines on the Swiss test road. The preview time during the before-condition in Switzerland was expressed as a mean of the preview times in Finland and in Portugal. Δt_{hyp} describes a hypothetical change in preview times, if increased visibility had not increased speed level at all.

Table 7.6 - Preview time before (t_b) and after (t_a) the painting of road markings.

Test stretch	**Country**	**t_b (Sec.)**	**t_a (Sec.)**	**Δt (Sec.)**	**ΔS (Meter)**	**Δt_{hyp} (Sec.)**
1	FIN	2,2	2,6	+0,4	+ 7	+0,3
Continuous	P	2,4	2,6	+0,1	+ 8	+0,3
R=100	CH	2,2*	3,9	+1,7	+38	+1,9
2	FIN	2,0	1,9	±0,0	– 1	±0,0
Broken	P	2,2	2,6	+0,3	+13	+0,5
R=300	CH	2,2*	3,1	+0,9	+26	+1,0
3	FIN	2,0	2,6	+0,6	+15	+0,6
Continuous	P	2,2	3,1	+0,9	+30	+1,1
R=300	CH	2,2*	4,3	+2,1	+36	+2,3
4	FIN	2,1	3,5	+1,3	+28	+1,3
Continuous	P	2,2	3,3	+1,1	+30	+1,1
R=100	CH	2,2*	4,3	+2,1	+38	+2,4
	FIN	2,1	2,1	±0,0	-	-
Control	P	2,3	2,1	-0,2	-	-
	CH	2,2*	2,2*	±0,0	-	-

The Δt in Table 7.6 shows that whenever visibility increased, the preview time also increased. The increase was very moderate in Finland and moderate in Portugal, whereas in Switzerland the increase in preview time was substantial.

Before the painting of road markings, the mean preview time was 2,2 seconds. Since the results in improvement in road marking visibility usually resulted in an increase in preview time, this may be interpreted as indicating that 2,2 seconds is a too short time.

When looking at the association of the change in visibility distance and the change in preview time, it can be immediately seen that the association is very strong (see figure 7.8). Figure 7.8 shows the quadratic association (including the 95 % confidence interval) between the increase in visibility distance (in metres) and the corresponding increase in the preview time (in seconds). The correlation coefficient obtained was r = 0,98. Despite the high correlation, the predictive value of the association is still low, mainly due to the small number of observations.

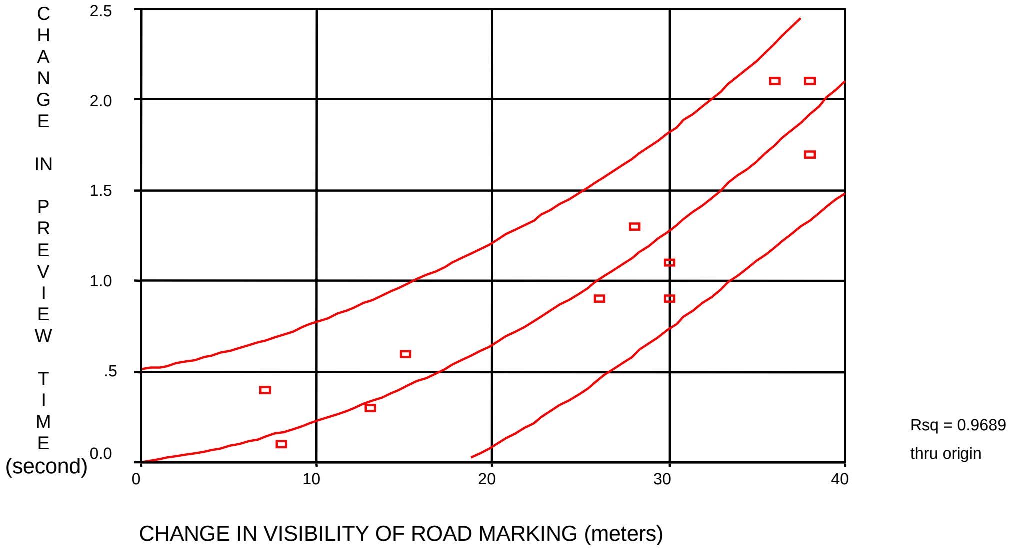


Figure 7.8 - The quadratic association between the change in visibility of road markings and the increase in the preview time.

Since speed is another factor in the concept of preview time, it can be seen in Δt that drivers do not fully compensate for the increase in preview time. The difference between Δt_{hyp} and Δt gives us directly the amount of the negative compensation (seconds) the increased visibility caused.

The difference ($\Delta t_{hyp} - \Delta t$) shows that drivers compensated only slightly for the increased visibility. The amount of compensation is only about 0,1 second on an average. This means that the subjects used only about 0,1 seconds of the increased preview time by increasing their speed.

The association of visibility and speed may also depend on the speed level prior to painting road markings. This speed level is partly determined by the road conditions associated with posted speed limits, but the speed limit does not explain it all as was seen in Portugal where the posted limits were exceeded by more than 10 km/h on average. In Switzerland the speed level was originally rather low, clearly lower than in Portugal. This may partly account for the relatively great speed increase in Switzerland when the visibility distances increased. There was also a fairly large increase in visibility distances in Portugal but not much speed increase possibly due to the originally very high speeds.

Studies on the simulator and from the field trials show that although increasing the visibility distance resulted in increased speeds, there was nevertheless an average increase of 1 second in preview times. In Switzerland, where the speeds increased most, the increase in preview time for continuous edge lines was about 2 seconds. This suggests that although drivers consumed some of the benefit by travelling faster, the greater part of the benefit was used to increase preview time. In effect, this meant that drivers had a bigger margin for error than before.

7.3.3 Lateral acceleration

Lateral acceleration was measured throughout the test road once a second and is expressed as g. The extreme lateral acceleration values are of special interest, since they are associated with the control of the vehicle. The extreme lateral acceleration is expressed here as the 99th percentile point values, which means that 1 % of the observations of the recorded data exceed these 99th percentile values in the relevant category.

There were considerably more lateral acceleration movements of the test vehicle to the left-hand side than to the right-hand side in the straight stretches. Generally, the changes were small between before-after-conditions no matter what stretch of the test road was looked at. Moreover, the acceleration values were of the same magnitude both in the left and right-hand movements of the car.

Even the extreme, 99th percentile lateral acceleration values expressed in g were generally moderate. Lateral acceleration values varied mainly between 0,15 g – 0,30 g.

There were very small differences between the control stretches and the stretches with road markings. In the data from Portugal, there are some indications of higher lateral acceleration values during the second driving period compared to the first period. This was seen in bends and in both the control and in the test stretches, and was evidently caused by the clear increase of speeds at some points during the second driving period.

In all, there are no indications in the data of too high lateral acceleration values despite the somewhat increased speed levels at several points after painting the road markings.

7.4 Conclusions

This study shed more light on the behaviour of drivers in conditions when new road markings have been introduced. Both objective measurements and driver interviews clearly indicated that road markings in most cases increase driving comfort. Only broken edge lines were not liked by a number of drivers.

New information was obtained about the effects of road markings on the lateral positioning of the car on the road. Wide edge lines change the extreme lateral positioning of the car somewhat more towards the centre of a road. However, broken edge lines seem to bring the car closer to the road edge. These observations are, however, tentative and improved methods for analysing the results might reveal more about drivers' lateral positioning on the road as a function of the introduction of new road markings.

From the results obtained in the field experiments, the following conclusions can be identified about the influence of road markings on drivers' behaviour:

- The field study carried out does not enable a recommendation for a safe preview time to be made. It seems that drivers use many sources of information besides visible road markings when steering a car. However, **the results of this field experiment suggest that the mean preview time obtained of 2,2 seconds is too short for driving comfort**.

- Road markings have an effect on the extreme lateral positioning of the car on the road. It seems that wide edge lines move the extreme positioning of the car somewhat towards the road centre. However, the opposite can be assumed concerning the broken edge lines.

- Increased visibility of road markings increased preview times, as drivers did not increase their speed so much that all the benefits were absorbed in higher speeds. This suggests that although drivers consumed some of the benefit (of more visible road markings) by driving faster, the greatest part of that benefit was used to increase preview time. This meant that drivers had a bigger margin for error than before.

Chapter 8. Design of road markings

8.1 Introduction

The scope of this chapter is to supply a scientific basis for future revision of national regulations and technical specifications for road marking. This chapter is therefore intended for use by experts and committees, and other individuals and bodies working in this field. This basis is provided by general guidelines for road marking design based on drivers' need. To facilitate detailed studies of the influence of local conditions, a computer programme for the visibility distance of road markings has been developed. This programme can be found on the attached CD-ROM.

Readers are assumed to be able to make the effort to study the field of road markings by means of the full reports and other literature, and to consider relevant national features of road marking, climate, traffic, drivers, roads and legislation.

For direct help for legislative purposes, annex D provides a survey of the geometry of longitudinal road marking in 15 countries and adds an analysis of the visibility distances for different assumptions concerning road marking reflectivity and other conditions. Further analysis may be carried out by means of the computer programme, supplied on the CD-ROM.

Additionally, the report and the computer programme, as well as other reports of COST 331 and other literature, may serve for educational purposes.

8.2 Criteria for design

8.2.1 Longitudinal road markings

Daylight and road lighting

For daylight, and for road lighting to the levels used for traffic routes in European countries, a contrast of minimum 0,6 between the road marking and the road surface ensures adequate visibility distances. (see chapter 5).

In daylight, road markings are visible at long distances, when the contrast between the road markings and the road surface exceeds a fairly small critical value. The same applies for road lighting, although the need for contrast is higher than for full daylight and the visibility distances obtained are shorter.

Contrast, on the other hand, may be ensured in most cases by application of appropriate classes Q1 to Q4 of the European standard EN 1436 for road markings (see in addition section 8.2.2). Classes Q1 to Q4 provide minimum levels for the luminance coefficient in diffuse illumination Qd of 80, 100, 130 and 160 $mcd \cdot m^{-2} \cdot lx^{-1}$ respectively.

For white road markings, classes Q3 or Q4 of the European standard EN 1436 are appropriate. These classes are technically and economically feasible, and are mostly met with road markings of common designs.

When the road surface is relatively dark, such as most asphaltic surfaces, class Q3 may be sufficient. When, the road surface is relatively light, such as cement concrete surfaces, class Q4 may be needed.

Road surfaces, in the dry condition, have Qd values in the range from 50 to 100 $mcd \cdot m^{-2} \cdot lx^{-1}$, or even higher. The lower end of the range applies for asphaltic road surfaces with dark stone aggregates, while the upper end of the range applies for asphaltic road surfaces with lighter stone aggregates and cement concrete surfaces. On very bright road surfaces, black surfaces are sometimes applied around road markings to enhance these. This is called contrast marking.

Contrast can alternatively be ensured by application of appropriate classes B1 to B5 specified in the European standard EN 1436. For road markings of special design and for yellow road markings, refer to sections 8.2.2 and 8.2.3 respectively. A contrast of 0,6 means that the road marking luminance is 60% higher than the road surface luminance.

Headlamp illumination

In headlamp illumination, visibility distances of road markings are mostly shorter than for daylight/road lighting conditions, and are influenced more strongly by other factors than the contrast between the road marking and the road surface.

In a limiting case approached in headlamp illumination, the primary factor is in fact not contrast, but 'signal' measured as the illuminance on the eyes of the driver by light reflected from the road marking.

The 'signal' is proportional to the surface area of the road marking as well as to the reflectivity[2] of the road marking

Accordingly, the surface area of the road marking is brought into play with almost as much influence as the reflectivity.

For longitudinal road markings, the surface area can be measured by the effective width of the road marking (see figure 8.1).

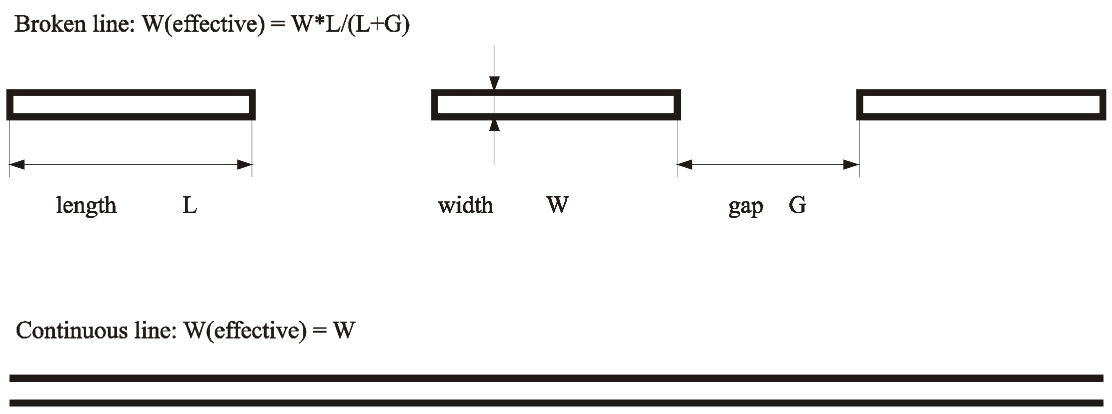


Figure 8.1 - Definition of effective width.

Figure 8.1 shows that a continuous line has an effective width equal to the actual width of the line, while a broken line has a reduced effective width.

[2] Reflectivity is measured by the coefficient of retroreflected luminance R_L defined in EN 1436.

Profiled road markings have effective widths defined the same way as for normal, plane road markings. This applies even for those types of profiled road markings that have gaps between profiles as shown in figure 8.2. Firstly, the gaps are normally not visible at sight distances relevant to driving, as also shown in figure 8.2. Secondly, even when gaps may be visible this is already accounted for to a first approximation by a reduction in the R_L value.

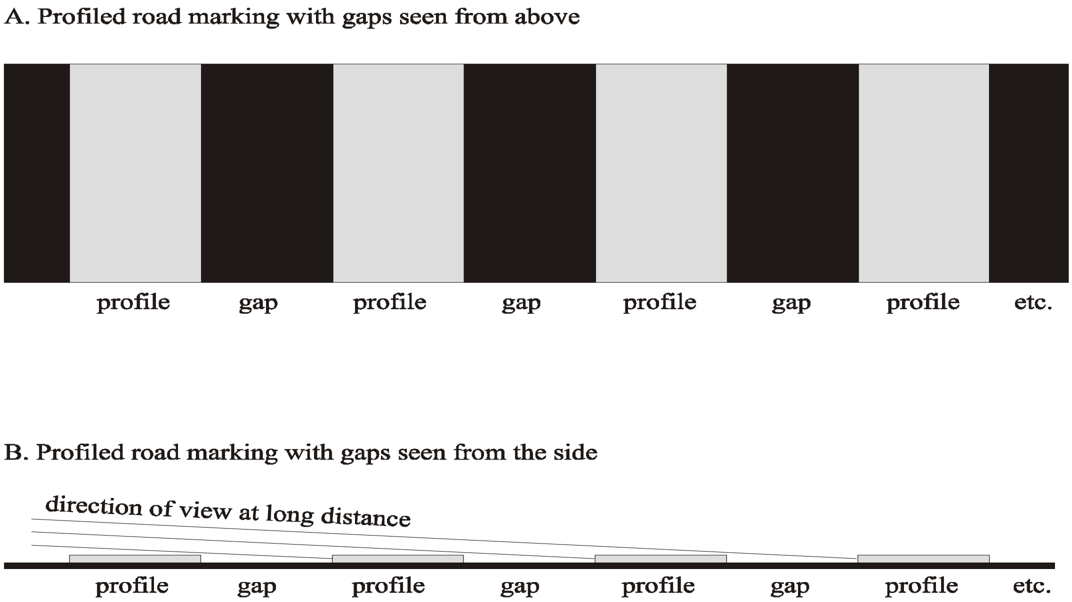


Figure 8.2 - Some profiled road markings have gaps (A), but these are normally not visible at sight distances relevant to driving (B).

Other factors relate to the age of the driver, the luminous intensities of the headlamp(s), the geometry of the vehicle, glare from oncoming vehicles, curvature of the road etc.

In order to investigate the influence of the effective width of the road marking, visibility distances have been calculated and reported in annex D for the road markings geometries of the state of the art report.

The calculations assume use of the low beam, which provides less good conditions than the high beam, but is usually unavoidable in view of traffic volumes on major roads.

R_L values as defined in classes R2 to R5 of the European standard EN 1436 are used. These, in combination with variations of the effective widths of the road markings, provide very large variations of 'signal'.

Classes R1 to R5 provide minimum levels of the coefficient of retroreflected luminance R_L of 80, 100, 150, 200 and 300 $mcd \cdot m^{-2} \cdot lx^{-1}$. Class R1 is used for yellow road markings, while classes R2 to R5 are relevant for white road markings.

In Annex D, results for conditions that are labelled 'ideal', 'medium' and 'adverse' can be found.

Even for 'ideal' conditions, visibility distances are often limited by the distances defined by the reach of the cut-off of the low beam.

These distances mostly ensure adequate preview time at the relevant driving speeds. Therefore, the longitudinal road markings of the state of the art report are adequate in combination with class R2 (R_L minimum, 100 $mcd \cdot m^{-2} \cdot lx^{-1}$) or higher - when conditions are ideal.

For 'adverse' conditions, on the other hand, the visibility distance falls short of the reach of the low beam for longitudinal road markings of small effective widths, and may no longer provide adequate preview time.

Accordingly, national regulations and technical specifications aiming at the visibility of road markings in headlamp illumination should be based not only on reflectivity, but also on the geometrical layout of the road markings and on the conditions considered to be of relevance.

'Ideal' conditions do occur, but only for drivers with good eyesight. 'Adverse' conditions may occur for most roads, at least for some drivers some of the time.

It is pointed out that the conditions included in annex D are meant as examples only, and that relevant conditions may depend on weather and traffic conditions and on national road classifications. An additional consideration may be the intended level of service to road users.

The computer programme referred to in the introduction can be used as a suitable tool to assist in establishing national regulations and technical specifications on the scientific basis provided in COST 331.

8.2.2 Profiled road markings

Wet conditions occur during rain and in periods after rain. Wet conditions occur also by dew formation on the road.

In some parts of Europe, wet conditions may occur relatively rarely and be of short duration only. In other parts of Europe, the road is damp more often and with longer duration. In some parts, including the Nordic countries, the road is even damp by dew formation during most of the winter period.

Wet conditions degrade the reflectivity and the visibility of road markings in headlamp illumination. The degree of degradation depends on the degree of wetness, but may cause almost total loss of reflectivity and visibility in some cases.

Road markings of special design to maintain some reflectivity in wet conditions are used in some countries as accounted for in the state of the art report. Profile is the most widely used design of such road markings.

For such road markings, the European standard EN 1436 provides classes of reflectivity for conditions during rain, and during wetness. The requirements of these classes are fairly low in recognition of the fact that road markings of special design can only ensure some reflectivity in wet conditions. However, even some reflectivity constitutes considerable improvement.

Accordingly, national regulations and technical specifications aimed at ensuring adequate visibility of road markings in headlamp illumination should include the use of profiled road markings and other special designs, when this is deemed necessary in view of climatic conditions.

Concerning profiled road markings, it should be taken into account that passage by a vehicle is accompanied by noise and vibration within the vehicle, and noise outside the vehicle.

Noise and vibration within the vehicle is an advantage for road markings that should not be crossed, such as edge lines, hatch fields and chevrons. For other road markings, such as lane dividing lines, noise and vibration is disadvantageous. Such markings can also cause stability problems for cyclists.

The noise outside the vehicle is offensive to persons in the neighbourhood of the road. Profiled road markings are therefore not generally used in built-up areas.

It should also be taken into account that profiled road markings can become virtually invisible when driving against the sun[3]. Therefore, profiled road markings are not recommended for centre lines with a legal message to the drivers, such as hazard lines.

8.2.3 Colour

Yellow road markings are inherently darker than white road markings, as the colour is produced by absorption of part of the spectrum of light. This is recognized in the European standard EN 1436 by provision of classes of performance for yellow road markings that are in some cases lower than for white road markings.

The inherent lower performance of yellow road markings may be counteracted by the use of other designs or layouts of road markings, such as increasing reflectivity or width of the markings. This in general implies higher costs or shorter functional life.

Accordingly, the basis for national regulations and technical specifications should take account of the following[4]:

1) Use of yellow road marking for permanent applications leads to either lower performance, or to higher costs, than white road markings.
2) It should be ensured that yellow road markings used for temporary applications have a performance which is at least as high as for existing, white road markings.

8.3 Visual criteria for road marking maintenance

Absolute criteria for maintenance are not provided, as the 'state of the art' report shows that there is no scientific basis for the criteria adopted in different countries, and as these criteria are often justified by local conditions and materials used, or by other local circumstances. An example is the 'winter problem' in some countries - the road is wet by dew formation throughout most of the winter.

Visual criteria should be based on performance and continuity, for instance:

- a continuous line should retain the appearance of being continuous;
- edge lines should not be missing in curves;
- double centre lines should be roughly equally visible.

[3] When driving against the sun, contrast is influenced by specular reflection. The contrast of a profiled road marking may become low, because of a low degree of specular reflection compared to the surrounding road surface.

[4] The state of the art report, and chapter 4, include an in depth analysis about the criteria followed in Europe for the use of yellow road markings.

A systematic approach may be based on the methods described in the "experimental" European standard ENV 13459 "Road marking materials - Quality control - Part 3 : Performance in use".

A road marking management system may provide advantages for the planning and execution of maintenance work. A management system should include threshold values for minimum performance at which maintenance is initiated. A management system may also include a method to predict when maintenance will be required based on a model for the depreciation of performance with time.

For the coefficient of retroreflected luminance, the threshold value for minimum performance should be set at 100 mcd·m^{-2}·lx^{-1}.

Chapter 9. Conclusions

The conclusions listed below are intended not only to reflect the major results obtained in the Action COST 331 but also to encourage road authorities and other relevant decision makers to accord to road markings the role they deserve as one of the most effective (i.e. with one of the highest **cost-benefit** ratios) low cost engineering measures available for improving road safety. The results of the Action provide scientific basis for future revision of national regulations and technical specifications for road marking.

1. The most commonly used criteria for recommending the application of road markings are the road width in combination with the average daily traffic (ADT) and the accident frequency. However, none of the participating countries in the Action appears to have carried out scientific research to support their current technical specifications or regulations on road markings.

2. The number of countries regulating the use of type 2 road markings (those designed to maintain night time visibility in adverse weather conditions) is still rather limited. However, even in the absence of national regulations, the use of type 2 road markings is restricted to longitudinal lines and on road sections outside urban areas (to avoid noise pollution). Indeed, the use of retroreflective road studs is not widespread in Europe and their use is inconsistent, in spite of the fact that they have shown their effectiveness in driving at night in adverse weather conditions.

3. The analysis of the existing models and the subsequent validation experiment allowed the design of a new methodology for the calculation of the visibility level for road markings. This new model may therefore be considered a replacement for the methodology given, for the same purpose, in CIE report N° 73. To facilitate the use of this methodology for analysing local conditions, a computer programme for the visibility distance of road markings has been developed and stored on the CD-ROM attached to this report.

4. The results of the cruise control condition, on the driving simulator, indicate that there is a minimum preview time for visibility of road markings of about 1,8 s. to keep the car with full control in the driving lane. A short time period should be added to allow the driver to look in his rear view mirrors and to read the instruments on the dashboard.

5. Drivers are in general very good at compensating for poor visibility conditions by reducing speed and by restricting the variation in lateral position to keep the car in the driving lane under full control. This is the main interpretation of the results from the condition of drivers' free choice of speed on the driving simulator.

6. The driver's preview time of 1,8 seconds to the visibility limit of road marking ahead should be regarded as the more general measure. It must though be kept in mind that this is an absolute minimum limit for safe driving.

7. The results of field experiments, on the influence of road markings on drivers' behaviour, confirms that increased visibility of road markings increased preview times as drivers did not increase their speed so much that all benefits were absorbed in higher speeds. **This suggests that although drivers consumed some of the benefit (of more visible road markings) by driving faster, the greatest part of that benefit was used to increase preview time, giving them a bigger margin for error than before.**

8. The results of COST 331 does not make it possible to quantify the effect of road markings on road safety nor to give clear answers to further questions such as the choice between a centre line or a edge line on a narrow road. Nevertheless, COST 331 has settled the necessary scientific basis and has developed the necessary background to design new experiments intended to provide answers to these other more specific questions in the field of road markings.

Chapter 10. Bibliography

The present list incorporates bibliographical references which have served as support for this work, as well as other useful publications and documents.

It has been made in order to collect and update the existing literature in the field of road markings.

The numbering does not refer to the main text. Bibliographical references are classified in four groups: International agreements, Articles and other documents, CIE reports and Standards.

10.1 International Agreements

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10.4 European standards

102. EN 1436 Road markings materials - Road marking performance for road users, 1997.

103. EN 1423 Road marking materials – Drop on materials – Glass beads, antiskid aggregates and mixtures of the two.

104. EN 1424 Road marking materials – Premix glass beads

105. EN 1463-1 Road marking materials – Retroreflecting road studs – Part 1: Initial performance requirements.

106. EN 1824 Road marking materials – Road trials

107. EN 1790 Road marking materials – Preformed road markings

109. ENV 13459-3 Road marking materials – Quality control – Part 3: Performance in use.

Annex A Visual Data for the calculation of visibility level

A.1 General

The calculation model for the visibility of targets used in the following is published by Dr. - Ing. Werner Adrian [1989].

The basic equation is given in section A.2. It is equivalent to the basic equation of the above mentioned model, but has been rearranged to provide more convenient expressions for calculation.

The influence of glare is considered in section A.3 and of the observer age in section A.4. The methods of these sections have also been rearranged for convenience of calculation.

It is assumed that road markings always have a positive contrast to the road surface, and therefore a correction available in the above mentioned calculation model for negative contrasts has been omitted.

Sections A.2, A.3 and A.4 provide the equations without comments or observations. Such are given in the sections A.5, A.6 and A.7.

A.2 Basic equation for the visibility level VL

The visibility level VL for a target depends on the size of the target α, the luminance difference between the target and the background ΔL and the background luminance L_b:

$$\mathbf{VL = \Delta L\times\alpha^2/(A+B\times\alpha)} \qquad \textit{(Equation A.1)}$$

where **α** is the target size in minutes of arc.
ΔL is the luminance difference in $cd\cdot m^{-2}$.
A and B are functions of the background luminance L_b in $cd\cdot m^{-2}$.
and **VL** is the visibility level.

The functions A and B are given by: *(Equation A.2)*

$$L_b \begin{cases} \geq 0{,}6: & \begin{cases} A = \log(10{,}086\times L_b^{0{,}2509})+0{,}27154\times L_b^{0{,}5867} \\ B = 0{,}09588\times L_b^{0{,}466} \end{cases} \\ < 0{,}00418: & \begin{cases} \log A = 0{,}2355+0{,}173\times\log L_b \\ \log B = -0{,}6835+0{,}5275\times\log L_b+0{,}0227(\log L_b)^2 \end{cases} \\ \text{in between:} & \begin{cases} \log A = 0{,}1355+0{,}3372\times\log L_b+0{,}0866(\log L_b)^2 \\ \log B = -1{,}0485+0{,}3190\times\log L_b \end{cases} \end{cases}$$

NOTE: The equation is rearranged as compared to the paper by Dr.-Ing. Werner Adrian. The functions A and B equal $(k\times\Phi)^{½}$ and $(k\times L)^{½}$ of that paper.

A.3 Influence of disability glare

The veiling luminance caused by disability glare is expressed by:

$$\mathbf{L_v = k\Sigma E/\theta^2} \qquad \text{(Equation A.3)}$$

where $\mathbf{L_v}$ is the veiling luminance in $cd \cdot m^{-2}$.
$\mathbf{k}$ is a constant of 9,2.
$\mathbf{E}$ is the illuminance in lx on the eye of the observer from a glare source.
$\boldsymbol{\theta}$ is the glare angle in degrees measured from the line of sight to the direction towards the glare source.
and $\boldsymbol{\Sigma}$ means summation for all glare sources.

The influence of disability glare on the threshold target size is obtained by substituting L_b by $L_b + L_v$ in equation A.2.

A.4 Influence of age

With age, the ocular transmission and the optical clarity of the eye both decrease. These effects are highly individual, data given below are averages for a number of test persons.

The first-mentioned effect of age is described by substituting ΔL with $\Delta L/AF1$ in equation A.1 and L_b with $L_b/AF1$ in equation A.2. AF1 is an age factor with values given by:

$$AF1 = \begin{cases} \text{Age from 20 to 44: } 0{,}0100 \times Age + 0{,}8 \\ \text{Age from 44 to 64: } 0{,}0282 \times Age \\ \text{Age from 64 to 80: } 0{,}1876 \times Age - 10{,}2 \end{cases} \qquad \text{(Equation A.4)}$$

The last-mentioned effect is described by multiplying the veiling luminance L_v as derived by equation A.3 with a factor AF2 before making the substitutions defined in section A.3. AF2 is given by:

$$AF2 = \begin{cases} \text{Age from 20 to 25: unity} \\ \text{Age from 25 to 80: } 1 + (0{,}0248 \times Age - 0{,}62)^2 \end{cases} \qquad \text{(Equation A.5)}$$

A.5 Comments on the basic equation

In laboratory situations, when observers know what to expect and have unlimited time for observation (2 seconds or more), a visibility level VL of unity is sufficient to ensure detection of the target with a high probability.

In traffic situations, on the other hand, the time for observation of each possible target is limited, and targets may have to be searched for. Dr.-Ing. Werner Adrian [1989] recommends the use of VL = 10 for certain detection.

Equation A.1 has an extreme case when the term $B \times \alpha$ is large compared to the term A, making VL roughly independent of the target size α ($VL \approx \Delta L/B^2$). This occurs when the contrast $C = \Delta L/L_b$ is small and defines the domain of Weber's law. Some typical limiting values of the contrast are given in table A.1.

> NOTE1: In conditions of road lighting and daylight, some road markings have such small contrast to the road surface that their visibility is governed by Weber's law. This means that the visibility distance may change from short to long with only small improvements in contrast.

Equation A.1 has another extreme case when the term $B \times \alpha$ is small compared to the term A, giving the target size α its full influence on the VL ($VL \approx \Delta L \times \alpha^2/A^2$). This occurs when the contrast $C = \Delta L/L_b$ is large and defines the domain of Ricco's law. Table A.1 contains some typical limiting values for this case also.

> NOTE2: In conditions of headlamp illumination, the contrast of road markings to the road surface is sometimes so high that their visibility is governed by Ricco's law. This means that the visibility depends strongly on the distance, and on the size (width and pattern) of road markings.

> NOTE3: For very small targets of high luminance, the term $\Delta L \times \alpha^2$ is proportional to the illuminance at the eye, which is the stimulus to the eye in such situations.

Table A.1 - Typical limiting values of the contrast, where the laws of Weber and Ricco apply. Values are for VL = 10.

Typical limiting values of the contrast $\Delta L/L_b$		Weber's law	Ricco's law	
at background luminance L_b:		close to:	above:	
headlamp lighting	0,001	0,76	25,0	(12')
headlamp lighting / road lighting	0,01	0,43	15,0	(6,3')
headlamp lighting / road lighting	0,1	0,19	6,8	(3,6')
road lighting	1	0,09	3,4	(2,6')
road lighting / daylight	10	0,08	2,8	(1,7')
daylight	100	0,07	2,4	(1,4')
daylight	1.000	0,06	2,2	(1,4')
	$cd \cdot m^{-2}$			

In between the two above mentioned extreme cases, the size of the target does have an influence on visibility, but not as strong as in the domain of Ricco's law.

In all cases, the contrast sensitivity increases with increasing background luminance, meaning that targets may be visible even when contrast or target size are smaller. This works up to the high levels of daylight conditions, where the contrast sensitivity saturates.

Table A.2 shows some values of the threshold target size α for some values of the contrast $\Delta L/L_b$ and the background luminance L_b.

Table A.2 - Values of the threshold target size α for VL = 10.

L_b		$\Delta L/L_b$: 0,1	1	10	100
headlamp lighting	0,001			22,7	5,7
headlamp lighting	0,01		58,0	8,1	2,2
headlamp lighting / road lighting	0,1		13,4	2,8	0,8
road lighting	1		5,8	1,4	0,4
road lighting / daylight	10	64,2	3,2	0,8	
daylight	100	30,8	2,4	0,6	
daylight	1.000	22,7	2,3	0,6	
	$cd \cdot m^{-2}$				

A.6 Comments on disability glare

In conditions of headlamp illumination and road lighting, the most severe sources of glare are headlamps of oncoming vehicles.

Consider a simple situation where:

- the observer drives his car on a straight road, looking straight ahead
- the observer meets a motorcycle with one headlamp using the dipped beam
- the luminous intensity I of the headlamp in directions towards the observer during the meeting is constant
- the lateral separation S of the driver and the motorcycle is constant during the meeting

At a point during the meeting, the distance between the two vehicles, as measured along the road, is D.

The illuminance E is $I/(D^2+S^2)$ and the angle θ is arctan(S/D). As long as the distance D is much larger than S, this can be approximated by $E = I/D^2$ and $\theta = 57{,}3 \times S/D$. Accordingly, the veiling luminance becomes $L_v = k \times E \times \theta^{-2} = 0{,}0028 \times I/S^2$.

The veiling luminance is seen to be constant in this simple meeting situation on a straight road. In practice, glare is less when the distance D is very large, among other reasons because of absorption in the atmosphere. Furthermore, glare does decrease in the last phase of the meeting, partly because the luminous intensity I decreases at wide angles to the road.

However, at a meeting on a straight road, glare does emerge at large distances, normally hundreds of metres, and does not decrease significantly until shortly before the two vehicles pass each other.

The level can be evaluated using a value of 200 cd for I, being typical, and a value of 3,5 m for S, corresponding to a meeting on a two lane road, giving a veiling luminance of $0{,}046\ cd \cdot m^{-2}$.

When meeting vehicles with more than one headlamp, perhaps with a higher luminous intensity, and perhaps several vehicles at a time, the veiling luminance may become as high as 1 $cd{\cdot}m^{-2}$ in some cases.

In the case of headlamp illumination, the background luminance of the road surface is mostly only a small fraction of 1 $cd{\cdot}m^{-2}$. So that glare from oncoming vehicles may be severe. In some cases, glare may shift the situation from the domain of Ricco's law to the domain of Weber's law, making it doubtful if road markings can be seen at any distance.

Even in the case of road lighting, where the luminance of the road surface is mostly in the range from 0,5 to 2 $cd{\cdot}m^{-2}$, glare from oncoming vehicles may be quite severe. The levels of road lighting have probably been set so as to be adequate to compete with glare.

The observer can reduce glare by looking away from the glare source, such as fixing his gaze on the edge line at some distance ahead, instead of looking straight ahead.

Furthermore, glare is strongly reduced by an increase of the lateral distance S. Accordingly, glare is much less, when driving in the near side lane on a four lane road, and is much less on a road with a central reserve.

For a realistic calculation of glare, all details of the geometry should be considered. However, the values of the veiling luminance given in table A.3 may be used for simplified evaluations.

Table A.3 - Values of the veiling luminance L_v in $cd{\cdot}m^{-2}$ by glare from oncoming cars.

number of on-coming cars:	lateral separation to oncoming cars: 3,5 m	7,0 m	10,5 m	14,0 m	17,5 m
1	0,098	0,024	0,011	0,006	0,004
2	0,196	0,049	0,022	0,012	0,008
3	0,294	0,073	0,033	0,018	0,012
4	0,392	0,098	0,044	0,024	0,016
5	0,490	0,122	0,054	0,031	0,020

A.7 Comments on the influence of age

Some values of the factors AF1 and AF2 defined in section A.4 are given in table A.4.

Table A.4 - Values of the factors AF1 and AF2 for the influence of age.

Age	20	30	40	50	60	70	80
AF1	1,00	1,10	1,20	1,41	1,69	2,93	8,81
AF2	1,00	1,02	1,14	1,38	1,75	2,25	2,86

The effect of age on the transmission of the eye (AF1) is like driving with sunglasses or with a tinted wind screen. The effect on the clarity of the eye (AF2) is like driving with a dirty or worn wind screen.

Judged by the values of table 4, the influence on visibility is perhaps not bad for the first-mentioned effect alone, but in combination with glare the influence must be considerable.

Annex B Driving experiment

B.1 Introduction

Annex A defines a basic equation A.1 for the visibility level VL using parameters defined for a laboratory situation with a circular target presented on a background, both with uniform luminance.

In terms of visibility of road markings in driving situations, a road marking is the object and the road surface is the background. However, the equation is not readily applicable, as road markings are generally not seen as circular objects and as the road marking and the road surface can have non-uniform luminance.

A translation is obviously required. The translation must include methods for substituting the road marking by a circular target of uniform luminance, and for determining the target and background luminance. The translation must be logical, and must provide correct results, at least to an acceptable approximation.

The scope of the driving experiment is to establish such a translation, and to supply data for testing it. A further aim is to determine the visibility level VL needed in driving situations.

The experiment was carried out by the Swedish Road and Transport Institute in the autumn of 1996. For practical reasons, the experiment included only situations of headlamp illumination and only longitudinal markings.

The experiment did however provide a fairly sound test of the proposed translation as the lines included both broken and continuous lines and as the conditions were varied considerably.

The experimental conditions are explained in section B.2, while the resulting visibility distances are given in section B.3.

A factor analysis of the results given in section B.4 shows that the parameters defining the experimental conditions influence the results strongly, leaving only a small residual variation. It is pointed out that conditions are in the domain of Ricco's law.

In section B.5, a translation is introduced and used to give calculated visibility distances in close agreement with those of the experiment.

B.2 Experimental conditions

Table B.1 summarizes the experimental conditions. The experiments were conducted on part of road 1050 in the central part of Sweden. The road is straight and flat, having been built on an old railway embankment. It was selected to avoid situations where road markings may be hidden by horizontal curves, or their visibility affected by vertical curves.

The road markings were in thermoplastic material, placed in a line in the centre of a driving lane, applied for the experiment and removed afterwards. The length was approximately 75 m, selected to be sufficient to simulate very long road markings. The spacing of driving lengths was at least 200 m in order to secure independent observations.

The road markings had four different patterns and two levels of retroreflection. Each of these eight types was repeated six times. Accordingly, a total of $6\times8 = 48$ sections of 75 m long road markings were applied to the road.

The aim for the two levels of retroreflection was values of the coefficient of retroreflected luminance R_L of 100 and 400 $mcd \cdot m^{-2} \cdot lx^{-1}$ respectively. The low level showed some variation for the four patterns, while the high level was established to a good approximation in all cases.

The test vehicle and its recording equipment is equipped for experiments of this nature and has been used on several previous occasions. For this particular experiment, three different lighting systems were used, providing clearly different levels of total luminous intensity.

The aim was to provide uniform intensities towards points along the road markings, so as to avoid the disturbing influence of the cut-off of the low beam and other variations.

The experiment involved nine observers, all in their twenties and with normal vision.

The method was to bring three observers through the road at a time, each with his own push button for recording detection of a road marking. Observers took part in three tours with the different lighting systems. The driving speed was kept at 90 km/h.

The retroreflection levels of the road markings and the road surface, i.e. R_L, were measured once and checked before each tour using an LTL2000 retrometer with the standard geometry defined in the European standard EN 1436.

The total luminous intensity of the headlamps was also measured once and tested before each tour. Measurements were made by the use of a photometer placed at the road and turned towards the headlamps.

The weather conditions were good with clear nights and dry road surface. If an opposing car was encountered, which happened rarely, the test vehicle was stopped at the road side for a moment before starting off again. A scout in a vehicle several kilometres ahead gave warnings.

Figure B.1 - Broken line: 3 + 9 m; width: 10 cm

Figure B.2 - Broken line: 3 + 3 m; width: 10 cm

Figure B.3 - Continuous line; width: 10 cm

Figure B.4 - Continuous line; width: 30 cm

Table B.1 - Experimental conditions.

The road is a two-lane road in rural conditions, it is straight and flat.

The R_L value, as an average along the road and measured in the geometry of EN 1436 is 7,9 $mcd \cdot m^{-2} \cdot lx^{-1}$.

The road markings were applied for the experiment and removed afterwards. They were of a length of appr. 75 m, spaced at least 200 m apart and placed in a line in the centre of a driving lane.

The pattern of road markings:

P(1) broken line 3+9 m, 10 cm

P(2) broken line 3+3 m, 10 cm

P(3) continuous line, 10 cm

P(4) continuous line, 30 cm

The retroreflection R_L of road markings:

$R_L(1)$ approximately 100 $mcd \cdot m^{-2} \cdot lx^{-1}$ *)

$R_L(2)$ approximately 400 $mcd \cdot m^{-2} \cdot lx^{-1}$ **)

*) the following values apply for $R_L(1)$:

P(1): 77 $mcd \cdot m^{-2} \cdot lx^{-1}$

P(2): 83 $mcd \cdot m^{-2} \cdot lx^{-1}$

P(3): 96 $mcd \cdot m^{-2} \cdot lx^{-1}$

P(4): 118 $mcd \cdot m^{-2} \cdot lx^{-1}$

**) 400 $mcd \cdot m^{-2} \cdot lx^{-1}$ applies for all patterns

The test vehicle is a Volvo 245 Station Wagon with a recording system for the position and equipped with indicators for three test persons at a time. The observer eye height is 1,2 m and the height of the headlamps 0,65 m.

The headlamps of the test vehicle:

I(1): two normal dipped beam headlamps aimed low (-2,5%) so that the sharp gradient from the cut-off is projected onto the road surface between 25 and 30 m in front of the car

I(2): I(1) plus four fog lamps aimed parallel to the road surface and dimmed

I(3): I(2): but with the fog lamps at full power

total luminous intensity of headlamps, measured in positions along the centre of the driving lane:

Distance	40	60	100	150	200	m
I(1)	1600	1270	1170	1100	1030	cd
I(2)	5700	6500	7200	7400	7400	cd
I(3)	20300	25000	28000	28700	29000	cd

B.3 Experimental visibility distances

The experimental visibility distances are shown in table B.2.

It may be noted that observers have individual levels of visibility distance, as is always the case in experiments of this nature. This may be due to individual eye vision and/or criteria for detection.

However, the visibility distances of the individual observers depend on the conditions in the same manner. The averages, also shown in table B.2, are used in the following.

Table B.2 - Experimental visibility distances.

conditions (see table B.1)	observer: 1	2	3	4	5	6	7	8	9	average
I(1) R_L(1) P(1)	34	40	42	39	41	39	44	45	39	40
P(2)	35	45	47	43	50	47	54	52	48	47
P(3)	45	60	64	62	63	66	72	71	70	64
P(4)	61	80	81	81	96	97	95	90	94	86
R_L(2) P(1)	50	63	70	66	78	75	69	59	76	67
P(2)	49	75	80	79	75	87	85	79	84	77
P(3)	60	85	98	93	100	101	104	85	89	91
P(4)	81	106	131	117	137	130	146	120	147	124
I(2) R_L(1) P(1)	41	56	65	49	51	57	65	53	60	55
P(2)	41	58	61	65	67	70	77	72	71	65
P(3)	58	89	99	89	91	96	104	104	107	93
P(4)	83	114	126	126	128	139	137	125	138	124
R_L(2) P(1)	68	86	99	96	95	96	115	93	115	96
P(2)	77	107	126	118	125	144	136	122	142	122
P(3)	88	122	142	133	151	139	161	131	143	135
P(4)	119	177	201	176	182	193	230	201	216	188
I(3) R_L(1) P(1)	61	76	84	73	79	88	96	93	92	82
P(2)	70	92	109	90	86	105	115	114	111	99
P(3)	105	146	146	120	124	150	157	184	166	144
P(4)	133	176	183	166	151	163	200	214	217	178
R_L(2) P(1)	97	125	134	134	116	129	152	164	168	136
P(2)	114	160	170	166	158	179	204	194	204	172
P(3)	129	173	181	163	148	174	196	202	206	175
P(4)	174	252	288	211	219	240	300	319	307	257

B.4 Factor analysis of the experimental visibility distances

Table B.3 shows a comparison of the average experimental visibility distances D1 to distances obtained by factor analysis D2.

Table B.3 - Comparison of average experimental visibility distances D1, distances obtained by factor analysis D2 and by the basic equation D3.

test conditions (see table B.1)	D1	D2	ΔD2	D3	ΔD3
I(1) R_L(1) P(1)	40	41	-1	40	0
P(2)	47	48	-1	48	-1
P(3)	64	61	3	59	5
P(4)	86	83	3	85	1
R_L(2) P(1)	67	63	4	64	3
P(2)	77	75	2	79	-2
P(3)	91	95	-4	97	-6
P(4)	124	129	-5	130	-6
I(2) R_L(1) P(1)	55	60	-5	57	-2
P(2)	65	71	-6	71	-6
P(3)	93	90	3	88	5
P(4)	124	122	2	124	0
R_L(2) P(1)	96	92	4	95	1
P(2)	122	110	12	113	9
P(3)	135	139	-4	137	-2
P(4)	188	188	0	194	-6
I(3) R_L(1) P(1)	82	86	-4	82	0
P(2)	99	102	-3	101	-2
P(3)	144	129	15	127	17
P(4)	178	175	3	176	2
R_L(2) P(1)	136	132	4	136	0
P(2)	172	158	14	162	10
P(3)	175	199	-24	192	-17
P(4)	257	270	-13	255	2
average	113	113	0	113	0
st. deviation			8 (6%)		7 (5%)

D1 is the average observation distance given in table B.2

D2 is an approximation to D1 by the following factor analysis: D2 = 40,7×FP×FR×FI m;

where:				
	P(1)	P(2)	P(3)	P(4)
FP =	1,000	1,194	1,503	2,042
	R_L (1)	R_L (2)		
FR =	1,000	1,549		
	I(1)	I(2)	I(3)	
FI =	1,000	1,462	2,099	

D3 is obtained by the basic equation A.1 for VL = 7,2

The factor analysis reproduces the experimental data quite well, with a small difference ΔD2 = D1-D2. The standard deviation is 8 m, and 6% in terms of percentage difference.

Variance analysis (not shown) confirms that the variation of the visibility distance is accounted for by the parameters, with only a small remaining variation. Each parameter has a strongly significant influence.

It may be noted that the variation of the visibility distance is accounted for by the parameters in an independent way. For example, a change of road marking pattern has a certain effect regardless of the retroreflection level.

It may also be noted that the amount of road surface covered by road marking, as reflected by the patterns P(1), P(2), P(3) and P(4), is as important as the retroreflection level.

As an example, the pattern P(3) corresponds to 4 times more road marking surface than P(1), while the retroreflection level $R_L(2)$ corresponds to an average of 4,3 times higher retroreflection than $R_L(1)$. The factor values are respectively 1,503 and 1,549.

These two features indicate that the conditions of the experiment are in the domain of Ricco's law, where size is as important as luminance (see section A.5).

B.5 Comparison to the basic equation for visibility

The basic equation A.1, see section A.2, can be applied when values for target size, target luminance and background luminance are available.

In this connection, the target is the road marking while the background is the road surface.

The luminance provided by a single headlamp at a given location is determined as the product of the illuminance at the location and the relevant R_L value (due to the definition of R_L). The illuminance is to be determined on a plane perpendicular to the direction of illumination (in practice a vertical plane will do).

The R_L value must correspond to the geometrical situation and, at least in principle, the total luminance provided by more than one headlamp simultaneously must be determined as the sum of individual contributions.

However, when the headlamps are mounted at the same height, the same R_L value applies, and the total luminance may be found as the total illuminance times the R_L value. The total illuminance, on the other hand, is the total luminous intensity I of the headlamps divided by the distance squared D^2.

This results in the following expression:

$$\mathbf{L = I \times R_L / D^2} \qquad \textit{(Equation B.1)}$$

where **L** is the luminance of the road marking or the road surface at a location.
I is the total luminous intensity of headlamps towards the location.
$\mathbf{R_L}$ is an R_L value reflecting the road marking or the road surface and the geometrical situation.
and **D** is the distance from the headlamps to the location.

The R_L values of table B.1 were measured in the standard geometry specified in the European standard EN 1436, corresponding to a headlamp mounting height of 0,65 m, an observer eye height of 1,2 m and a distance of 30 m.

The test vehicle aims at the same heights of headlamp and observation, while the relevant distances cover a range from about 40 m and upwards. However, according to the report No. 6 of the Nordic Research Cooperation for night traffic, the R_L value is roughly constant at distances from 30 m and upwards.

Accordingly, measured R_L values given in table B.1 are used directly in equation B.1 to provide luminance values.

Remaining questions are addressed in view of the fact that conditions during the experiment are in the domain of Ricco's law, where the stimulus to the eye is the illuminance at the eye from the target.

The illuminance at the eye dE from a short section of a road marking of length dD at a distance D is given by $I\times R_L \times W \times H_o \times dD \times D^{-5}$, where W is the width of the line and H_o is the eye height. For a continuous line, when assuming a constant intensity I of the headlamps, the total illuminance becomes:

$$\mathbf{E = 0{,}25 \times I \times R_L \times W \times H_o \times dD \times D_1^{-4} \times (1{,}0 - (D_1/D_2)^4)} \qquad \textit{(Equation B.2)}$$

where **D1** and **D2** are distances to the front and the back ends of the marking respectively

The value of the last term in this expression $(1{,}0-(D_1/D_2)^4)$ ranges from 0 to unity for a very short and a very long road marking respectively. It is interesting that relatively short road markings provide almost the full value of the term. For instance, when the length D_2-D_1 is 50% of the distance to the front D_1, the value is as high as 0,82.

This shows that those parts of the road marking closest to the observer contribute much more to visibility than parts further away.

The road markings in the experiment, of a length of 75 m, may be considered as very long, except perhaps in cases corresponding to the longest visibility distances.

Furthermore, the intensity value I of the headlamps towards the front end of the road marking is more important than values towards more distant locations. When consulting table B.1, this shows that an assumption of a constant intensity is relatively safe.

In any case, the illuminance at the eye can be determined for a continuous line by means of equation B.2. A circular target of a uniform luminance L and a size given by a solid angle ω provides the same stimulus when $L\times\omega = E$, where ω is measured in steradians.

A sensible choice of L is the luminance of the road marking at the front, as this is probably where the observer is looking at the moment of detection. The solid angle is determined by $\omega = E/L$ to be converted to the diameter α of a circular target. The luminance of the road surface at the same location serves as the background luminance L_b.

Expressions like the one of equation B.2 could be derived for the broken lines of patterns P(1) and P(2). However, a detailed analysis of a pattern at a certain instant of time is probably not justified in view of the visual process, which certainly takes some time. In any case, the results would be close to those obtained by equation B.2 for a continuous line of the same surface area as the broken line.

Accordingly, the broken lines of patterns P(1) and P(2) are handled as continuous lines with reduced widths of respectively 2,5 and 5 cm.

On this basis, visibility levels VL are computed for the visibility distances D1 given in table B.3. The VL's turn out to be on average 7,2 with some variation from case to case (values are not shown). Adjusting the distances to provide a VL of 7,2 results in the computed distances D3 also given in table B.3 and shown in figure B.5 as well.

The fit between computed and experimental visibility distances is good, with small differences $\Delta D3 = D1\text{-}D3$. The standard deviation is 7 m, and 5% in terms of percentage difference.

The fit is surprisingly good in view of the adjustment of only one parameter value (VL of 7,2), translation from complex to simple conditions, uncertainty regarding true conditions and approximations regarding constant headlamp intensity I and length of road markings, etc.

This result indicates that the translation is sensible, that conditions are well controlled and that approximations are permissible.

It may be noted that the only real uncertainty of the translation is the choice of background luminance, which is not very important in the conditions of the experiment.

It may also be noted that it does require quite large changes in conditions to produce a significant change in the visibility distance. This can be verified by examples based on equation B.2, showing that the stimulus changes in proportion to the distance to the power of -4.

Finally, a VL of 7,2 has been used because it provides the best fit to the experimental data. Otherwise, the value cannot be justified and may contain some sort of correction for conditions or approximations. However, it is not unreasonable that the experiment should result in a lower value of VL than the value recommended for practical traffic situations (VL = 10, see section A.5 of Annex A).

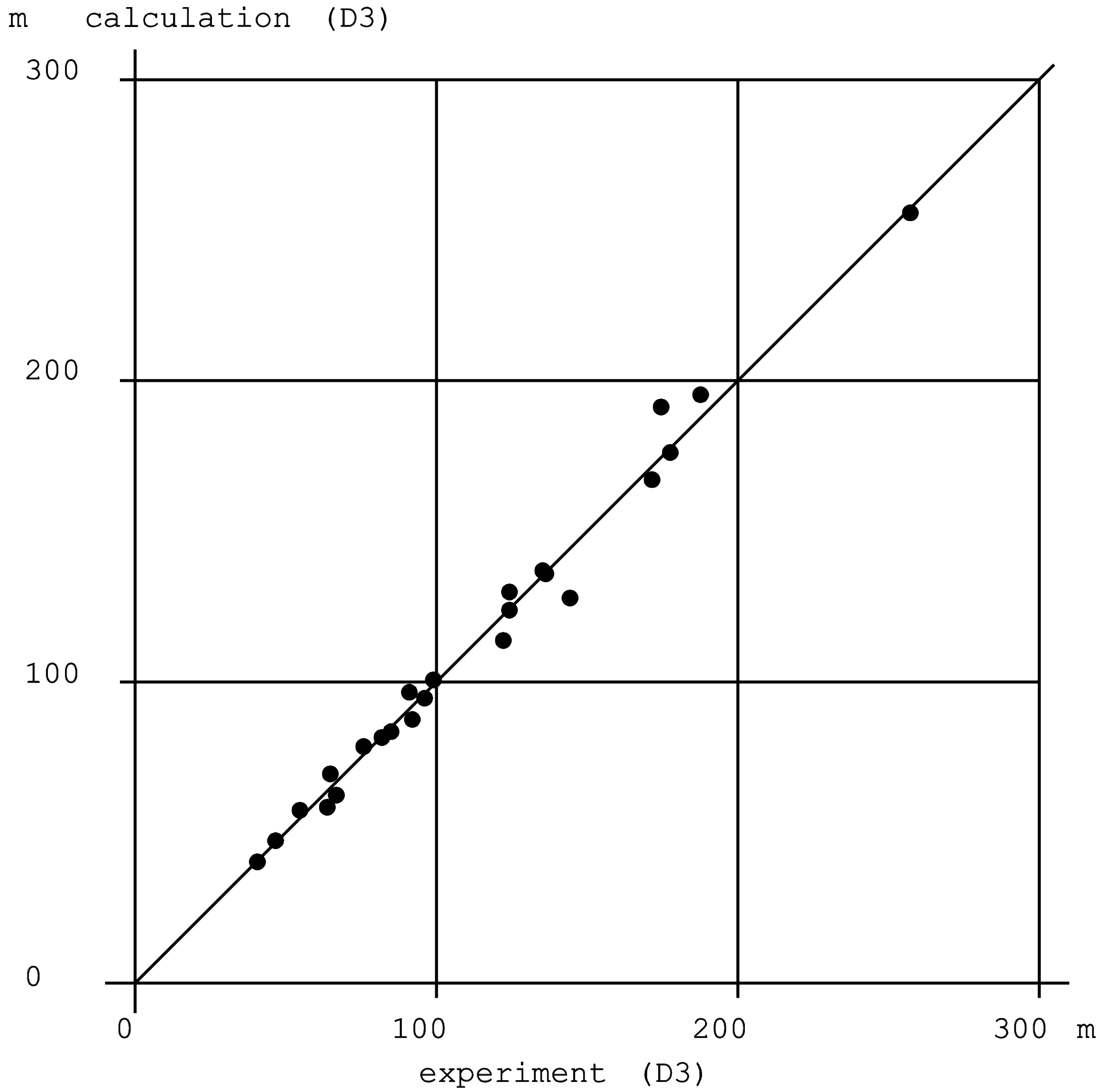

Figure B.5 - Comparison between experimental and calculated visibility distances

Annex C Example of calculation of visibility distance

The example developed in this annex is for night driving on high beam with the following assumptions and data:

1) Young driver - implying that substitutions for age described in annex A are not required.

2) There is no glare or other veiling luminance - implying that the substitution for glare described in annex A is not required.

3) The headlamp intensity I is constant at 10.000 cd in all relevant directions.

4) The vehicle is a passenger car with two headlamps and an observer eye height H_o of 1,2 m.

5) The road marking is continuous, has a width W of 0,1 m and starts at a distance D = 96 m in front of the driver.

6) The road surface has an R_L value of 15 $mcd \cdot m^{-2} \cdot lx^{-1}$ which implies a relatively, but not very dark, road surface.

7) The road marking has an R_L value of 100 $mcd \cdot m^{-2} \cdot lx^{-1}$ just meeting the minimum requirement of class R2 in the European standard EN 1436.

8) The vehicle geometry is such that R_L values measured for the standard geometry (i.e. according to EN 1436) can be applied directly for both headlamps, assuming some simplification.

The definition of the coefficient of retroreflected luminance is $R_L = L/E$, where L is the luminance of the road marking or road surface created by one headlamp, and E is the illuminance (lx) created by that headlamp at the location of the road marking on a plane perpendicular to the direction of illumination.

Accordingly, the luminance created by one headlamp is $L = R_L \times E$. The distance law of illumination says that $E = I/D^2$, so that $E = (10.000\ cd)/(96\ m)^2 = 1{,}09\ lx$. The luminance of the road surface created by one headlamp is $L = (15\ mcd \cdot m^{-2} \cdot lx^{-1}) \times (1{,}09\ lx) = 16{,}4\ mcd \cdot m^{-2} = (16{,}4\ mcd \cdot m^{-2})/(1.000\ mcd \cdot m^{-2}/cd \cdot m^{-2}) = 0{,}0164\ cd \cdot m^{-2}$. The two headlamps together produce twice this luminance, i.e. approximately 0,033 $cd \cdot m^{-2}$. In the same way, the luminance of the road marking is 0,218 $cd \cdot m^{-2}$.

Having determined the luminances of the road surface and the road marking, the equivalent target size of the road marking must be determined as well. The definition says that the equivalent target size is the size of a circular target of the same solid angle ω (sr) as obtained by luminance weighted integration over the surface of the road marking.

This integration is generally tedious; the computer programme stored on the CD-ROM attached to this report performs it numerically. In this case, however, the integral can be performed analytically; the result of $\omega = 0{,}25 \times H_o \times W/D^2$ is provided in chapter 5. This results in $\omega = 0{,}25 \times (1{,}2\ m) \times (0{,}1\ m)/(96\ m)^2 = 0{,}0000032$ sr.

It should be taken into account that the driver sees the road marking as a triangle with a base equal to the line width W and a height equal to his eye height H_o, having an area of $0,5 \times H_o \times W$ and a solid angle of $0,5 \times H_o \times W/D^2$. This result is true if the luminance of the road marking is constant. In headlamp illumination, however, this is not the case making the factor value decrease from 0,5 to 0,25.

The equivalent target size α is measured as the angular diameter of the equivalent circular target in the unit of minutes of arc ('). According to chapter 5: $\alpha = 3879 \sqrt{\omega}$ which leads, for this example, to a value for α = 6,94'.

Finally, the visibility level VL is found by use of the basic equation $VL = \Delta L \times \alpha^2/(A+B \times \alpha)^2$. The value for the equivalent target size α of 6,94' can be inserted directly. The value of the luminance difference ΔL is determined as the difference between the luminances of the road marking and the road surface, leading to $0,218 - 0,033\ cd \cdot m^{-2} = 0,185\ cd \times m^{-2}$. A and B are functions of the background luminance L_b, for which the road surface luminance serves.

The expressions for A and B are:

$$L_b \begin{cases} \geq 0,6: & \begin{cases} A = \log(10,086 \times L_b^{0,2509}) + 0,27154 \times L_b^{0,5867} \\ B = 0,09588 \times L_b^{0,466} \end{cases} \\ < 0,00418: & \begin{cases} \log A = 0,2355 + 0,173 \times \log L_b \\ \log B = -0,6835 + 0,5275 \times \log L_b + 0,0227(\log L_b)^2 \end{cases} \\ \text{in between:} & \begin{cases} \log A = 0,1355 + 0,3372 \times \log L_b + 0,0866(\log L_b)^2 \\ \log B = -1,0485 + 0,3190 \times \log L_b \end{cases} \end{cases}$$

The third case 'in between' is relevant for the value of $0,033\ cd \cdot m^{-2}$. Results are A = 0,670 and B = 0,030.

The basic equation gives:

$$VL = (0,185\ cd \cdot m^{-2}) \times (6,94')^2/(0,670 + 0,030 \times 6,94') = 10$$

This is the visibility level required for real traffic situations, referred to in chapter 5. Accordingly, the visibility distance is actually the 96 m used in the example. It should be noted that repeating the calculations for other distances shows that VL is strongly dependent on the distance.

Annex D Visibility of longitudinal road markings in headlamp illumination

D.1 Introduction and discussion

This annex contains an analysis of visibility distances of longitudinal road markings in headlamp illumination.

The longitudinal road markings have the geometries accounted for in fifteen countries in the state of the art report (refer to section D.2).

The visibility distances have been calculated using the programme described in Appendix 4. Refer to sections D.3 and D.4 regarding conditions for calculations, results and discussion.

Some of the calculations are carried out for ideal conditions, assuming a young driver, powerful headlamps and absence of glare and other veiling luminance.

For such conditions, the visibility distance is mostly close to the distance at which the cutoff of the low beam of the headlamps meets the road. In the circumstances of the calculations, this distance is about 60 m for road markings to the left of the driver, and about 100 m for road markings to the right[5].

Assuming that drivers need a minimum of 2 second preview time (see chapter 6), the shorter of the above-mentioned distances of 60 m allows driving speeds up to about 110 km/h. The longer distance of 100 m allows high driving speeds.

The almost constant visibility distance is obtained in spite of wide ranges of effective widths and reflectivity (coefficient of retroreflected luminance, R_L). Visibility distances in excess of the cut-off are obtained only for combinations of large effective widths and high reflectivity.

Other calculations are carried out for less good conditions exemplified by greater age of the driver, less efficient headlamps and occurence of glare. For these conditions, the visibility distance decreases down to about half of the distance of the cut-off of the low beam.

Such conditions are realistic, more common than ideal conditions, and will occur for most roads, at least for some drivers in some periods. Even worse conditions occur during rain or wetness, but have not been included in the calculations.

5 The distance is longer for road markings to the right of the vehicle, due to the elevated part of the beam being to the right for right-hand traffic. For left-hand traffic, the longer distance is for road markings to the left.

D.2 Geometry of longitudinal road markings

The geometries for fifteen countries described in the state of the art report are included. The countries are indicated in table D.1, while geometries are accounted for in tables D.3, D.4 and D.5 for motorways, interurban dual carriageway roads and interurban single carriageway roads respectively.

Tables D.3, D.4 and D.5 show also the effective width of the road markings, which is the average width along the road taking gaps of broken lines into account. The ranges of the effective width are given in Table D.2.

The above-mentioned tables show that the fifteen countries use several different road marking geometries and that the ranges of effective widths are quite large.

Table D.1 - Fifteen countries.

Symbol:	Country:
B	Belgium
CH	Switzerland
D	Germany
DK	Denmark
E	Spain
F	France
FIN	Finland
G	Greece
ICE	Iceland
IRL	Ireland
NL	the Netherlands
P	Portugal
S	Sweden
SLO	Slovenia
UK	United Kingdom

Table D.2 - Ranges of effective widths.

Road type:	Line type:	Effective width:
Motorways	left line	7,5 to 30 cm
	lane line	2,2 to 5 cm
	right line	7,5 to 30 cm
Dual carriageway	left line	3,3 to 30 cm
	lane line	1,7 to 10 cm
	right line	3,3 to 30 cm
Single carriageway	centre line	2,5 to 10 cm
	edge line	3,3 to 30 cm

Table D.3 - Geometry of longitudinal road markings on motorways.

Effective width	Geometry			
	Length	Gap	Width	Country
Left line:				
7,5 cm	20 m	20 m	15 cm	IRL
20 cm	continuous	continuous	20 cm	CH+E+FIN+ NL+P+SLO+ UK
22,5 cm	continuous	continuous	22,5 cm	F
25 cm	continuous	continuous	25 cm	CH+G
30 cm	continuous	continuous	30 cm	B+D+DK+S
Lane line:				
2,2 cm	2 m	7 m	10 cm	UK
2,5 cm	3 m	9 m	10 cm	NL+FIN
2,9 cm	5 m	12 m	10 cm	E
3,3 cm	4 m	8 m	10 cm	IRL
	2 m	7 m	15 cm	UK
3,5 cm	3 m	10 m	15 cm	F
3,8 cm	3 m	9 m	15 cm	G+S
4 cm	2,5 m	10 m	20 cm	B
4,3 cm	4 m	10 m	15 cm	P
5 cm	5 m	10 m	15 cm	CH+DK
do	6 m	12 m	15 cm	D+SLO
Right line:				
7,5 cm	20 m	20 m	15 cm	IRL
14,3 cm	20 m	4 m	20 cm	E
16,4 cm	38 m	14 m	22,5 cm	F
20 cm	continuous	continuous	20 cm	CH+FIN+NL +P+SLO+UK
25 cm	continuous	continuous	25 cm	CH+G
30 cm	continuous	continuous	30 cm	B+D+DK+S

Table D.4 - Geometry of longitudinal road markings on interurban dual carriageway roads.

Effective width	Geometry			
	Length	Gap	Width	Country
Left line:				
3,3 cm	1 m	2 m	10 cm	S
7,5 cm	20 m	20 m	15 cm	IRL
10 cm	continuous	continuous	10 cm	NL+ICE+DK
12 cm	continuous	continuous	12 cm	D
15 cm	continuous	continuous	15 cm	NL+SLO+UK
18 cm	continuous	continuous	18 cm	F
20 cm	continuous	continuous	20 cm	CH+E+FIN+ G+P+UK
25 cm	continuous	continuous	25 cm	CH
30 cm	continuous	continuous	30 cm	B+DK
Lane line:				
1,7 cm	1 m	5 m	10 cm	UK[1)]
2,2 cm	2 m	7 m	10 cm	UK
2,5 cm	3 m	9 m	10 cm	FIN+ICE+S
2,8 cm	3 m	10 m	12 cm	F
2,9 cm	5 m	12 m	10 cm	E
3,3 cm	5 m	10 m	10 cm	DK
3,3 cm	4 m	8 m	10 cm	G+IRL
3,8 cm	3 m	9 m	15 cm	S
4 cm	4 m	8 m	12 cm	D
4 cm	2,5 m	10 m	20 cm	B
4,3 cm	4 m	10 m	15 cm	P
5 cm	5 m	10 m	15 cm	SLO
5 cm	6 m	12 m	15 cm	CH
6,7 cm	6 m	12 m	20 cm	CH
10 cm	continuous	continuous	10 cm	NL[2)]
Right line:				
3,3 cm	1 m	2 m	10 cm	S
7,5 cm	20 m	20 m	15 cm	IRL
10 cm	continuous	continuous	10 cm	ICE+NL+DK
10,6 cm	20 m	14 m	18 cm	F
12 cm	continuous	continuous	12 cm	D
15 cm	continuous	continuous	15 cm	NL+SLO+UK
16,7 cm	20 m	4 m	20 cm	E
20 cm	continuous	continuous	20 cm	CH+FIN+G+ P+UK
25 cm	continuous	continuous	25 cm	CH+D
30 cm	continuous	continuous	30 cm	B+DK

[1)] used only on roads with speed limit of 60 km/h
[2)] it is not quite certain that this line is continuous

Table D.5 - Geometry of longitudinal road markings on interurban single carriageway roads.

Effective width	Geometry			
	Length	Gap	Width	Country
Centre line:				
2,5 cm	2 m	6 m	10 cm	CH+ICE
2,5 cm	3 m	9 m	10 cm	FIN+S
2,8 cm	3,5 m	9 m	10 cm	E
2,8 cm	3 m	10 m	12 cm	F
3 cm	2,5 m	10 m	15 cm	B
3,3 cm	2 m	4 m	10 cm	UK
3,3 cm	4 m	8 m	10 cm	G
3,3 cm	5 m	10 m	10 cm	DK
3,4 cm	4 m	10 m	12 cm	P
3,6 cm	4 m	7 m	10 cm	G
3,8 cm	3 m	9 m	15 cm	IRL+S
4 cm	4 m	8 m	12 cm	D
5 cm	2 m	4 m	15 cm	UK
5 cm	3 m	6 m	15 cm	CH+UK
5 cm	5 m	10 m	15 cm	SLO
10 cm	continuous	continuous	10 cm	NL[1]
10 cm	continuous	continuous	2* 5 cm 2*10 cm	[2]
20 cm	continuous	continuous		[2]
Edge line:				
3,3 cm	1 m	2 m	10 cm	S
5 cm	3 m	3 m	10 cm	ICE
7,5 cm	20 m	20 m	15 cm	IRL
8,3 cm	3 m	3,5 m	18 cm	F
10 cm	continuous	continuous	10 cm	FIN+ICE+
				NL+UK+D
12 cm	continuous	continuous	12 cm	K
15 cm	continuous	continuous	15 cm	D
				CH+E+NL
20 cm	continuous	continuous	20 cm	+
25 cm	continuous	continuous	25 cm	P+SLO+U
30 cm	continuous	continuous	30 cm	K
				B+CH+G
				B
				DK

[1] it is not quite certain that this line is continuous
[2] double continuous lines have been added

D.3 Calculations and results

Calculations are performed by means of the computer programme (described in appendix 4) with use of the following input:

1) The right-hand traffic option of the computer programme. Results apply for left-hand traffic, when considering the left line to be the right line and vice versa.

2) Ideal, medium and adverse conditions as described in table D.6. Actual use of conditions is mentioned in table captions.

3) The 'passenger car' option of the computer programme.

4) The 'low beam' headlamp option of the computer programme.

5) Straight and flat roads.

6) Positions of the road marking 1,5 m to the left of the vehicle for left lines, lane lines and centre lines, and 1,5 m to the right of the vehicle for right lines and edge lines.

7) Effective widths of the road markings as accounted for in the previous section.

8) An R_L value for the road surface of 15 $mcd{\cdot}m^{-2}{\cdot}lx^{-1}$ meant to represent a relatively dark, but not very dark, asphalt concrete surface. An additional R_L value of 30 $mcd{\cdot}m^{-2}{\cdot}lx^{-1}$ used for motorways is meant to represent cement concrete surfaces.

9) R_L values for the road marking of 100, 150, 200 and 300 $mcd{\cdot}m^{-2}{\cdot}lx^{-1}$ corresponding to classes R2, R3, R4 and R5 in EN 1436 of relevance for white road markings[6]. Actual use of conditions is shown in table captions.

Results of tables D.7 and D.8 are for motorways, while results of tables D.9 and D.10 are for dual carriageway interurban roads and single carriageway interurban roads respectively. All tables include results for 'ideal', 'medium' and 'adverse' conditions as described in table D.6.

D.4 Discussion of results

Figure D.1 shows the reach of the cut-off of low beam headlamps, when mounted on the passenger car. The reach is about 60 m and 100 m for road markings to the left and right respectively.

The reach explains the visibility distance of some of the cases of tables D.7, D.8, D.9 and D.10, where the road marking needs to have some part within the cut-off. Only combinations of 'ideal' conditions, large effective width and high reflectivity leads to visibility distances beyond the cut-off.

In some cases, on the other hand, the visibility distance is not close to the reach of the cut-off and may be as low as half of that reach.

The tables also provide the visibility distances that are needed for 2, 3 and 5 seconds of preview at some relevant driving speeds.

[6] The above-mentioned R_L values are in the scale of the standard measuring geometry on EN 1436 and do not necessarily apply at the actual conditions of the tables.

For the 'ideal' conditions of table D.6, the driver is young, the headlamp intensities correspond to powerful headlamps, and there are no oncoming vehicles causing glare.

More relevant situations may be reflected by the 'medium' and 'adverse' conditions of table D.6, where drivers are not young, headlamp intensities are lower due to degradation and dirt and oncoming vehicles cause glare.

Sometimes conditions are even worse, e.g. during rain or wetness, or during winter in some countries.

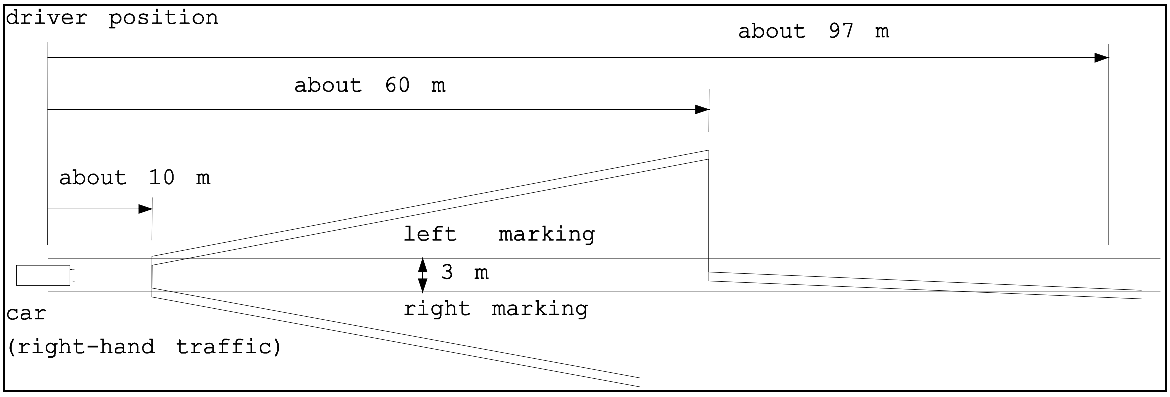

Figure D.1 - Reach of the cut-off of low beam headlamps for a passenger car driving in a 3 m wide lane.

Table D.6 - Three sets of conditions labelled 'ideal', 'medium' and 'adverse'.

Conditions	Age of driver	Headlamp intensity*)	Glare L_v
Ideal Medium Adverse	young 50 year 60 year	100% 50% 30%	no glare 0,25 $cd{\cdot}m^{-2}$ 0,50 $cd{\cdot}m^{-2}$
*) refers to percentage of 10.000 cd in directions below the cut-off of the low beam			

Table D.7 - Visibility distance of longitudinal road markings on motorways. The R_L of the road surface is 15 mcd·m^{-2}·lx^{-1}.

Motorways	R_L of road marking (mcd·m^{-2}·lx^{-1}):			
	100	150	200	300
Effective width:	visibility distance (m) for adverse-medium-ideal conditions [1)]			
Left line:				
7,5 cm	42-56- 59	49-60- 61	53-60- 67	60-60- 76
20 cm	49-60- 66	57-60- 76	60-60- 84	60-60- 97
22,5 cm	49-60- 68	58-60- 78	60-60- 86	60-60-100
25 cm	50-60- 70	59-60- 80	60-60- 88	60-60-103
30 cm	52-60- 73	60-60- 83	60-60- 93	60-60-109
Lane line: [2)]				
2,2 cm	34-45- 54	39-49- 57	42-53- 58	47-57- 59
2,5 cm	35-46- 54	40-51- 57	43-54- 58	49-58- 59
2,9 cm	36-48- 55	41-52- 58	45-55- 59	50-59- 61
3,3 cm	36-49- 56	42-53- 58	46-57- 59	51-60- 63
3,5 cm	37-50- 56	42-54- 58	46-57- 59	52-60- 63
3,8 cm	37-51- 57	43-55- 58	47-58- 59	53-60- 65
4 cm	38-51- 57	43-55- 59	48-59- 59	53-60- 65
4,3 cm	38-52- 57	44-56- 59	48-59- 60	54-60- 67
5 cm	39-54- 58	45-58- 59	50-60- 61	55-60- 69
Right line:				
7,5 cm	42-58- 79	49-67- 86	54-73- 91	62-81- 97
14,3 cm	47-66- 87	55-75- 95	61-82- 99	69-84-104
16,4 cm	48-67- 89	56-77- 96	62-84-100	71-84-105
20 cm	49-70- 91	57-80- 98	64-84-102	73-85-106
25 cm	50-72- 94	59-83-101	66-84-104	76-89-107
30 cm	52-75- 96	61-84-102	68-84-105	78-92-109

[1)] Visibility distances apply for night-time driving in a passenger car on low beam, on a straight and plane road. Adverse, medium and ideal conditions relate to the age of the driver, to the intensity of the headlamps and to glare; refer to table D.6.

[2)] Lane lines are placed to the left of the vehicle.

required visibility distance:

	110 km/h:	120 km/h:	130 km/h:
2 s preview time:	61 m	67 m	72 m
3 s preview time:	92 m	100 m	108 m
5 s preview time:	153 m	167 m	181 m

Table D.8 - Visibility distance of longitudinal road markings on motorways. The R_L of the road surface is 30 mcd·m^{-2}·lx^{-1}.

Motorways	R_L of road marking (mcd·m^{-2}·lx^{-1}):			
	100	150	200	300
Effective width:	visibility distance (m) for adverse-medium-ideal conditions [1)]			
Left line:				
7,5 cm	39-51- 57	46-59- 59	51-60- 63	58-60- 73
20 cm	45-60- 60	54-60- 71	60-60- 80	60-60- 92
22,5 cm	45-60 -67	55-60- 73	60-60- 82	60-60- 95
25 cm	46-60 -62	56-60- 75	60-60- 84	60-60- 97
30 cm	47-60 -65	57-60- 78	60-60- 88	60-60-101
Lane line: [2)]				
2,2 cm	31-40- 49	37-47- 54	41-51- 56	46-55- 58
2,5 cm	32-41- 50	38-48- 55	42-52- 57	47-56- 59
2,9 cm	33-42- 51	39-49- 56	43-53- 57	49-58- 59
3,3 cm	34-44- 52	40-51- 56	44-54- 58	50-59- 59
3,5 cm	34-45- 53	40-51- 56	45-55- 58	51-59- 59
3,8 cm	34-45- 53	41-52- 57	45-56- 58	51-60- 62
4 cm	35-45- 53	41-53- 57	46-56- 58	52-60- 63
4,3 cm	35-46- 54	42-53- 57	46-57- 59	53-60- 64
5 cm	36-48- 55	43-53- 58	48-59- 59	54-60- 66
Right line:				
7,5 cm	39-53- 72	47-63- 81	52-70- 87	60-79- 95
14,3 cm	43-60- 80	52-72- 90	58-79- 96	68-84-102
16,4 cm	44-62- 81	53-73- 91	60-81- 97	69-84-103
20 cm	45-64- 83	55-76- 94	62-84- 99	72-84-104
25 cm	46-66- 87	56-79- 97	64-84-102	74-87-106
30 cm	47-68- 89	58-82- 99	66-84-103	77-90-107

[1)] Visibility distances apply for night-time driving in a passenger car on low beam, on a straight and plane road. Adverse, medium and ideal conditions relate to the age of the driver, to the intensity of the headlamps and to glare; refer to table D.6.

[2)] Lane lines are placed to the left of the vehicle.

required visibility distance:

	110 km/h:	120 km/h:	130 km/h:
2 s preview time:	61 m	67 m	72 m
3 s preview time:	92 m	100 m	108 m
5 s preview time:	153 m	167 m	181 m

Table D.9 - Visibility distance of longitudinal road markings on interurban dual carriageway roads. The R_L of the road surface is 15 ($mcd{\cdot}m^{-2}{\cdot}lx^{-1}$).

Dual carriageway roads	R_L of road marking ($mcd{\cdot}m^{-2}{\cdot}lx^{-1}$):			
	100	150	200	300
Effective width	visibility distance (m) for adverse-medium-ideal conditions [1)]			
Left line:				
3,3 cm	36-48- 56	42-53- 58	46-57- 59	51-60- 63
7,5 cm	42-56- 59	49-60- 61	53-60- 67	60-60- 76
10 cm	44-59- 59	51-60- 65	56-60- 72	60-60- 81
12 cm	45-60- 60	52-60- 68	58-60- 75	60-60- 84
15 cm	47-60- 62	54-60- 72	60-60- 78	60-60- 89
18 cm	48-60- 65	56-60- 75	60-60- 82	60-60- 94
20 cm	49-60- 66	57-60- 76	60-60- 84	60-60- 96
25 cm	50-60- 70	59-60- 80	60-60- 88	60-60-103
30 cm	51-60- 73	60-60- 83	60-60- 93	60-60-109
Lane line: [2)]				
1,7 cm	32-42- 52	37-47- 55	40-50- 57	45-54- 59
2,2 cm	34-44- 54	39-49- 57	42-53- 58	47-57- 59
2,5 cm	35-45- 54	40-51- 57	43-54- 58	49-58- 59
2,8 cm	35-46- 55	41-52- 57	44-55- 59	50-59- 60
2,9 cm	36-47- 55	41-52- 58	45-55- 59	50-60- 61
3,3 cm	36-48- 56	42-53- 58	46-57- 59	51-60- 63
3,8 cm	37-49- 57	43-55- 58	47-58- 59	53-60- 65
4 cm	38-55- 57	43-55- 59	48-59- 59	53-60- 65
4,3 cm	38-55- 57	44-56- 59	48-59- 60	54-60- 67
5 cm	39-55- 58	45-58- 59	50-60- 61	55-60- 69
6,7 cm	41-55- 58	48-60- 60	52-60- 65	58-60- 74
10 cm	44-59- 59	51-60- 65	56-60- 72	60-60- 81
Right line:				
3,3 cm	37-49- 70	42-56- 77	46-61- 81	53-68- 87
7,5 cm	42-58- 79	49-67- 86	54-73- 91	62-81- 97
10 cm	44-62- 82	52-71- 90	57-77- 95	65-84-100
10,6 cm	45-62- 83	52-71- 91	58-78- 96	66-84-101
12 cm	45-64- 84	53-73- 92	59-79- 97	67-84-102
15 cm	47-66- 87	55-76- 95	61-83- 99	70-84-104
16,7 cm	48-68- 89	56-78- 96	62-84-100	71-84-105
20 cm	49-70- 91	57-80- 98	64-84-102	73-85-106
25 cm	50-72- 94	59-83-101	66-84-104	76-89-107
30 cm	52-75- 96	61-84-102	68-84-105	78-92-109

1) Visibility distances apply for night-time driving in a passenger car on low beam, on a straight and plane road. Adverse, medium and ideal conditions relate to the age of the driver, to the intensity of the headlamps and to glare; refer to table D.6.
2) Lane lines are placed to the left of the vehicle.

required visibility distance:

	80 km/h:	90 km/h:	100 km/h:	110 km/h:
2 s preview time:	44 m	50 m	56 m	61 m
3 s preview time:	67 m	75 m	83 m	92 m
5 s preview time:	111 m	125 m	139 m	153 m

Table D.10 - Visibility distance of longitudinal road markings on interurban single carriageway roads. The R_L of the road surface is 15 (mcd·m^{-2}·lx^{-1}).

Single carriageway roads	R_L of road marking (mcd·m^{-2}·lx^{-1}):			
	100	150	200	300
Effective width	visibility distance (m) for adverse-medium-ideal conditions [1]			
Centre line:				
2,5 cm	35-45- 54	40-51- 57	43-54- 58	49-58- 59
2,8 cm	35-46- 55	41-52- 57	44-55- 59	50-59- 60
3 cm	36-47- 55	41-52- 58	45-56- 59	50-59- 61
3,4 cm	37-48- 56	42-54- 58	46-57- 59	52-60- 63
3,6 cm	37-49- 56	43-54- 58	47-58- 59	52-60- 64
3,8 cm	37-49- 57	43-55- 58	47-58- 59	53-60- 65
4 cm	38-50- 57	43-55- 59	48-59- 59	53-60- 65
5 cm	39-52- 58	45-58- 59	50-60- 61	55-60- 69
10 cm	44-59- 59	51-60- 65	56-60- 72	60-60- 81
20 cm	49-60- 66	57-60- 76	60-60- 84	60-60- 97
Edge line:				
3,3 cm	37-49- 70	42-56- 77	46-61- 81	53-68- 87
5 cm	39-54- 75	46-62- 81	50-67- 85	57-74- 92
7,5 cm	42-58- 79	49-67- 86	54-73- 91	62-81- 97
8,3 cm	43-59- 80	50-68- 87	55-74- 92	63-82- 99
10 cm	44-62- 82	52-71- 90	57-77- 95	65-84-100
12 cm	45-64- 84	53-73- 92	59-79- 97	67-84-102
15 cm	47-66- 87	55-76- 95	61-83- 99	70-84-104
20 cm	49-70- 91	57-80- 98	64-84-102	73-85-106
25 cm	50-72- 94	59-83-101	66-84-104	76-89-107
30 cm	52-75- 96	61-84-102	68-84-105	78-92-109

[1] Visibility distances apply for night-time driving in a passenger car on low beam, on a straight and plane road. Adverse, medium and ideal conditions relate to the age of the driver, to the intensity of the headlamps and to glare; refer to table D.6.

required visibility distance for 2 s preview time:
80 km/h: 44 m   90 km/h: 50 m   100 km/h: 56 m

required visibility distance:

	80 km/h:	90 km/h:	100 km/h:
2 s preview time:	44 m	50 m	56 m
3 s preview time:	67 m	75 m	83 m
5 s preview time:	111 m	125 m	139 m

Appendix 1 - Members of the Management Committee

The members of COST 331 were from 15 COST countries: Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Italy, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland and the United Kingdom. These are shown on the map in figure A1.1.

Each participating country signed a Memorandum of Understanding whereby their Governments agreed to co-ordinate their research effort toward meeting the aims of COST 331.

The execution of COST 331, while supported by the European Commission, has been directed by a Management Committee drawn from the Membership - the latter comprised government representatives, academics, and other experts in the field.

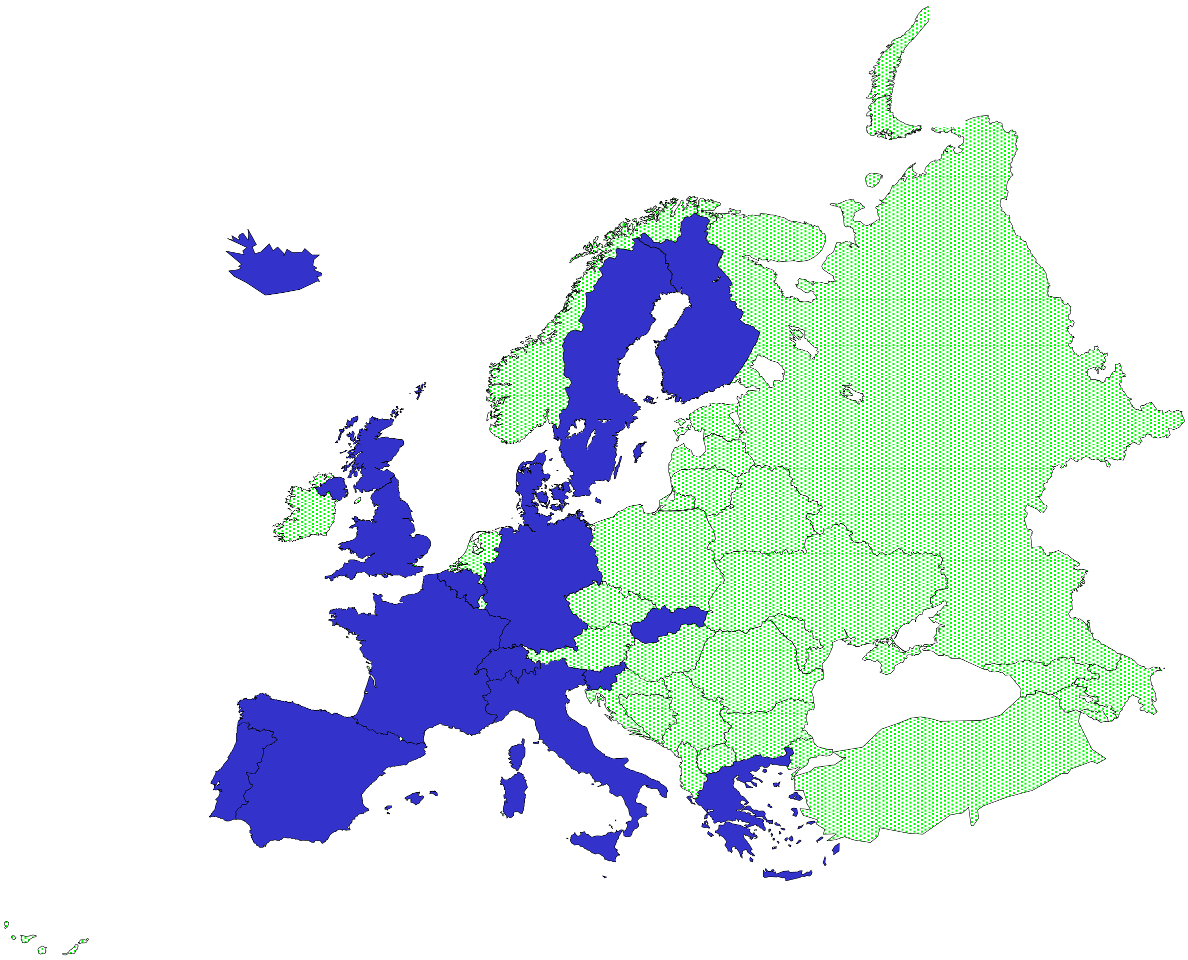

Figure A1.1 - Membership of COST 331 Management Committee

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Appendix 2 - Memorandum of Understanding - Technical Annex

Background summary

At present, most national technical specifications in the field of road markings lay down more or less appropriate minimum values for the parameters which define their essential requirements (night-time and daytime visibility and anti-skid properties) without always taking into account the real visibility needs of drivers.

Most research in this area, both national and international, concentrates on:

- development of new marking products which meet the above mentioned requirements for as long as possible (maximum useful life), and

- design of new technologies for the manufacture of high-performance equipment for assessing those requirements.

The proposed research is quite distinct from the work of the CEN TC226-WG2 group, which is concerned with the establishment of criteria with which marking products would need to comply in order to attain the CE marking.

What is therefore needed, is an up-to-date scientific method with which, on the basis of harmonized minimum values for the essential requirements of road markings, to determine the optimum pavement marking design in order to ensure that it is visible, by day and by night, in all weather conditions.

Nevertheless, "COST Action 331 " (hereinafter referred to as the "Action") should take into consideration the foreseeable time-frame for the completion of corresponding European standards (CEN TC226-WG2) so that any specific European requirements can be produced in time to provide participating countries with information to influence further developments and amendments of these standards.

Description of the action

Objectives

It is proposed to confine the project to continuous horizontal road marking (including road studs, directional arrows and chevrons). The project would cover permanent road markings.

The project would not cover vertical signs.

Discussion of the secondary objectives led to the following list being adopted:

- the state of the art in the area falling within the project's scope;
- establishment of guidelines to define road marking geometry;
- definition of road marking parameters;
- establishment of guidelines for road marking maintenance;
- identification of the visibility threshold required by the driver (including maximum luminance);
- study of the influence of road marking, visibility on the use of different colours (white and yellow);
- mechanical and noise effects produced by road marking;
- establishment of guidelines related to environmental protection and traffic flow.

Expected Synergic Results

In addition to helping to harmonize the level of road safety throughout the European road network, the creation of a scientific basis on which to establish homogeneous criteria for the effectiveness of road markings for the various types of road in the network will:

- provide a scientific method of setting harmonized criteria for optimum design and quality of road markings;
- assess the present level of quality of road markings and establish criteria for upgrading it, if necessary (maintenance guide);
- speed up the study and development of new, more effective and profitable products (acceptable cost/benefit ratio).

Lastly, by unifying these criteria we can rationalize the application of their assessment parameters and therefore their subsequent perfection and development.

Current State of Knowledge in the proposed Field of Research

For the most part, the Member States (and the other leading technological countries) have not given sufficient attention to the problem of optimum road marking as an indispensable element within road safety. There has, however, been some progress, notably in Denmark, France and Germany.

Most research in this area, both national and international, concentrates on:

- development of new marking products which meet the requirements for as long as possible (maximum useful life), and
- design of new technologies for the manufacture of high-performance equipment for assessing those requirements.

No previous European research in the field of application of the Action has been executed.

Grounds for Research and Results Expected

1. The basic purpose of this research is to provide a scientific basis on which to "harmonize" the quality and design of road markings and thus promote a uniformly high level of safety throughout the European road network.

   Road markings are in fact "traffic signals" with a decisive impact on driver safety, for the following reasons:

   (i) they are non-verbal (their message being expressed through shape and colour) and therefore readily understood by drivers;

   (ii) in poor light or bad weather the information we pick up from the environment becomes less reliable and road markings become particularly important.

   Unfortunately, the absence, in most cases, of the necessary scientific basis has led to significant differences in regulations on the visibility requirements and the geometry of road markings in the European Union.

   It is therefore essential that a "guidance" system as clear and effective as this should be based on solid design criteria which help harmonize the level of road safety in the European road network by standardizing the essential features of its horizontal signalization.

2. inter alia the following results may be expected:

   - optimization of a mathematical model with which to calculate, on the basis of observation parameters and the aforementioned essential requirements of the road markings, the minimum distance at which they should be visible in any conditions (by day, by night, with clear skies, during rain, etc.);

   - definition of the impact in road safety of the mechanical and noise effect of the profile road markings and the use of retroreflective road studs in horizontal signalization;

   - establishment of a guideline for design and maintenance of the pavement markings.

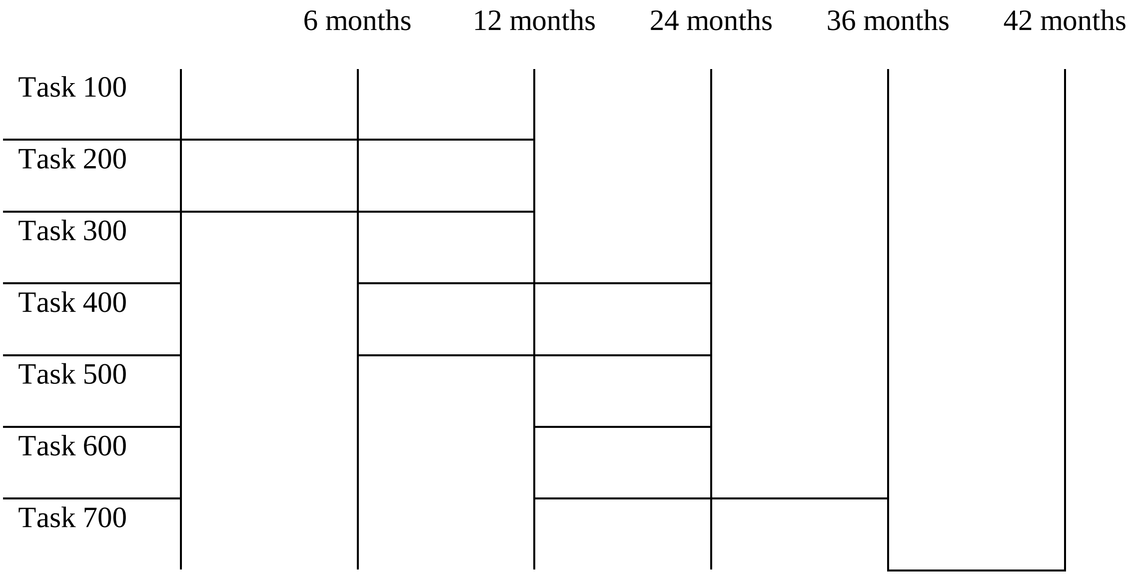
Organization of the Action

1. Workplan

   - Task 100: State of the art in the area falling within the project's scope.
   - Seminar:
   - Task 200: Interviews with the relevant individuals in the Member States to clarify current policies.
   - Task 300: Evaluation of drivers' visual needs.
   - Task 400: impact on road safety of the mechanical, visual and noise effects of road markings.
   - Task 500: Impact of road studs on road marking visibility and on mechanical and noise effects.

- Task 600: Establishment of guidelines for road marking design, application and maintenance.
- Task 700: Preparation of final report.

Timetable



2. Task distribution:

- each task will be coordinated by a Committee member;
- all countries volunteered to participate in the abovementioned tasks.

In particular, the tasks of the Committee will be:

- to ensure the flow of information;
- coordination and harmonization of the individual reports (each task would be covered in an interim report, which would constitute a chapter of the final report);
- supervision of the results of the different studies/activities;
- discussion and approval of the final draft report and the accompanying conclusion/recommendations;
- organization of a Workshop to disseminate the results of the Action.

Duration of the Action

The Action will last for three and a half years (1995-1998).

Estimation of the cost

The value of the "know-how", testbed results and studies that the different participants will feed into the Action is estimated to be ECU 1,3 million.

Appendix 3 - COST Transport overview

COST Transport is one of 17 domains existing in COST at the present time.

It was to be one of the seven areas seen as best suited for this new form of collaboration, which was officially set up by a Ministerial Conference in November 1971.

The Transport area lends itself particularly well to the COST framework, both because it combines aspects from a number of disciplines, and because of the need for harmonisation at European level. Liaison with the Transport Ministries and Administrations in the various countries is a key element of these COST Actions.

The COST Transport Secretariat is located within the Directorate General for Transport of the European Commission. The location with the staff managing the Fourth and Fifth Framework Transport RTD Programme, as well as the proximity with the Common Transport Policy Directorates, enables close collaboration between Transport Research activities and serves as a basis for further political action.

COST Transport Actions are authorised and supervised by the COST Technical Committee on Transport which, in turn, reports to the COST Committee of Senior Officials. Both of these decision-making bodies comprise representatives of the national governments of the COST countries.

By the end of 1999, the COST Transport domain comprised 13 ongoing Actions, with a total estimated cost of EURO 42.5 Million. 32 Actions have been completed, and a further 4 Actions have been selected and are under preparation.

Completed Actions

COST 30:	Electronic Traffic Aids on Major Roads
COST 30 bis:	Electronic Traffic Aids on Major Roads: Demonstration Project and Further Research
COST 301:	Shore Based Marine Navigation Systems
COST 302:	Technical and Economic Conditions for the Use of Electric Road Vehicles
COST 303:	Technical and Economic Evaluation of National Dual-mode Trolleybus Programmes
COST 304:	Use of Alternative Fuels in Road Vehicles
COST 305:	Data System for the Study of Demand for Interregional Passenger Transport
COST 306:	Automatic Transmission of Data Relating to Transport
COST 307:	Rational Use of Energy in Interregional Transport
COST 308:	Maintenance of Ships
COST 309:	Road Weather Conditions
COST 310:	Freight Transport Logistics
COST 311:	Simulation of Maritime Traffic
COST 312:	Evaluation of the Effects of the Channel Tunnel on Traffic Flows
COST 313:	Socio-economic Cost of Road Accidents
COST 314:	Express Delivery Services
COST 315:	Large Containers
COST 317:	Socio-economic Effects of the Channel Tunnel
COST 318:	Interactions between High-speed Rail and Air Passenger Transport
COST 319:	Estimation of Pollutant Emissions from Transport

COST 320: The Impact of E.D.I. on Transport
COST 321: Urban Goods Transport
COST 322: Low Floor Buses
COST 323: Weigh-in-Motion of Road Vehicles
COST 324: Long Term Performance of Road Pavements
COST 325: New Pavement Monitoring Equipment and Methods
COST 326: Electronic Charts for Navigation
COST 328: Integrated Strategic Transport Infrastructure Networks in Europe
COST 329: Models for Traffic and Safety Development and Interventions
COST 330: Teleinformatics Links between Ports and their Partners
COST 331: Requirements for Horizontal Road Marking
COST 333: Development of New Bituminous Pavement Design Method

Actions Underway

COST 327: Motorcycle Safety Helmets
COST 332: Transport and Land-Use Policies
COST 334: Effects of Wide Single Tyres and Dual Tyres
COST 335: Passengers' Accessibility of Heavy Rail Systems
COST 336: Use of Falling Weight Deflectometers in Pavement Evaluation
COST 337: Unbound Granular Materials for Road Pavements
COST 339: Small Containers
COST 341: Habitat Fragmentation due to Transportation Infrastructure
COST 342: Parking Policy Measures and their Effects on Mobility and the Economy
COST 343: Reduction in Road Closures by Improved Maintenance Procedures
COST 344: Improvements to Snow and Ice Control on European Roads and Bridges
COST 345: Procedures Required for Assessing Highway Structures
COST 346: Emissions and Fuel Consumption from Heavy Duty Vehicles

Actions in preparation

COST 338: Drivers' Visual Information Overload
COST 340: Towards a European Intermodal Transport Network: Lessons from History
COST 347: Pavement Research with Accelerated Loading Testing Facilities
COST 348: Reinforcement of Pavements with Steel Meshes and Geosynthetics

Up-to-date information on COST Transport can be found on the World Wide Web, at the following address: http://www.cordis.lu/cost-transport/home.html.

Appendix 4 - Computer programme for the visibility distance of road markings

A4.1 Introduction

The computer programme uses the methods described in chapter 5 and has equipment described in terms of:

- driver, vehicle and glare

  The programme has options for the driver's age in steps of 10 years from 20 to 80. Internally, this leads to the setting of factors for reduction of transmission and of optical clarity of the eye with age.

  The programme has further options for right-hand or left-hand driving. In either case, options for the vehicle are a passenger car, a bus/lorry or a motorcycle.

  The driving speed in km/h is input also.

  Glare is introduced directly by indication of a value of a veiling luminance L_v ($cd \cdot m^{-2}$). The value should be indicated for a twenty year old driver, as the programme converts to the actual driver age.

- road marking geometry and location

  The programme operates with a single, longitudinal road marking. The input is the width of the road marking and an indication of whether it is continuous or broken. If broken, the lengths of lines and gaps are to be input as well.

  The programme further operates with a single driving lane, whose width is to be input. The centre of the vehicle is in the middle of the driving lane, while the road marking is at the edge to the right or the left of the lane as indicated.

- road geometry

  The road can be made to curve horizontally and/or vertically.

  The input includes options for a straight road, or a road curving to the right or the left. For curving roads, additional input is the radius of the horizontal curve.

  The input includes further options for a flat road, or a road curving upwards or downwards. For curving roads, additional input is the radius of the vertical curve.

- headlamp illumination and coefficients of retroreflected luminance R_L

  The input includes options for headlamp(s) off, on low beam or on full beam. For headlamp(s) on, the input includes a factor for the headlamp luminous intensity, and values for the coefficients of retroreflected luminance R_L for the road marking and the road surface.

  The headlamp intensity distributions for the low and the high beam are constructed to represent new and fairly powerful headlamps in a simplified manner. The beams have intensities of 10.000 cd.

  The factor for the headlamp luminous intensity is used to reduce the intensities to represent old and/or dirty headlamps.

- daylight/road lighting and luminance coefficient in diffuse illumination Qd

  The input includes options for diffuse illumination off or on. If on, the input includes a value of illuminance on the horizontal plane, and values for the luminance coefficient in diffuse illumination Qd for the road marking and the road surface.

  Diffuse illumination is an approximation to daylight illumination in cloudy conditions, and to road lighting as an average for different locations on the road surface.

  The two forms of illumination supplied by the programme, i.e. headlamp illumination and daylight/road lighting can be used alone or together.

The programme computes the visibility distance for the assumption that a driver needs a visibility level VL of 10 of a road marking to see it with relative ease in a traffic situation. The preview time at the indicated driving speed is computed also.

The programme further computes and presents a visual image of the road scene as seen in perspective by the driver. The image can be analysed in terms of local luminance by the movement of a cursor.

The programme has a help function that refers to a fairly extensive document on the programme and its input. The document and parts of it may be printed.

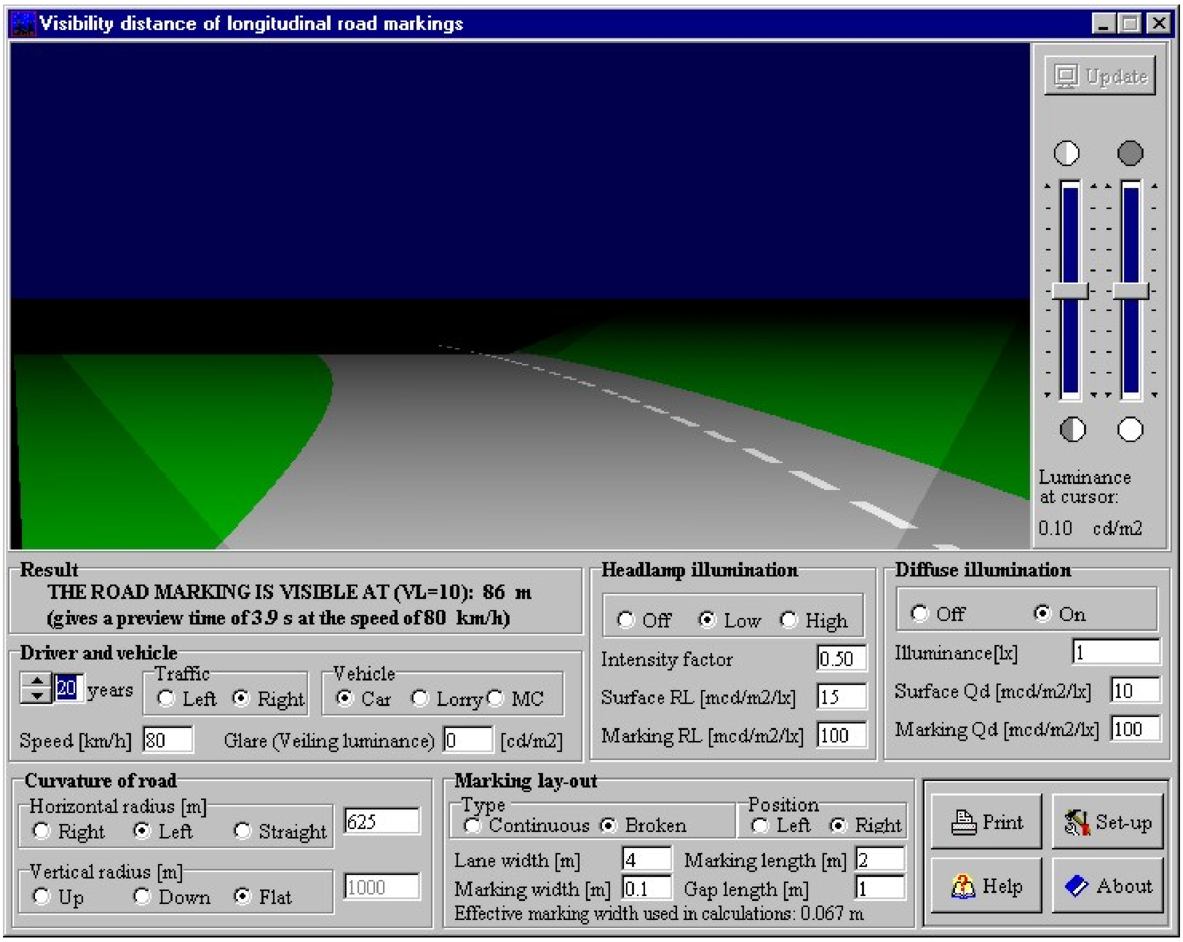


Figure A4.1 - Window used by the computer programme.

A4.2 Driver, vehicle and glare

The programme is based on the assumption that a driver needs a visibility level VL of 10 of a road marking to see it with relative ease in a traffic situation.

The driver's field of view is limited to ±5° in the vertical plane and ±10° in the horizontal plane. Parts of a road marking outside this field do not contribute to the visibility of the road marking[7].

The programme has options for the driver's age in steps of 10 years from 20 to 80. Internally, this leads to setting of values of the factors AF1 and AF2 as indicated in table A4.1. The factor AF1 relates to reduction of the transmission of the eye with age, while the factor AF2 relates to reduction of the optical clarity of the eye with age.

As an example, table A4.1 indicates that a sixty year old driver needs 1,69 times as much light, and experiences 1,75 times as much glare, as a twenty year old driver. However, it is pointed out that the data of table 1 are averages for a number of test persons, and that visual performance and effects of age are highly individual.

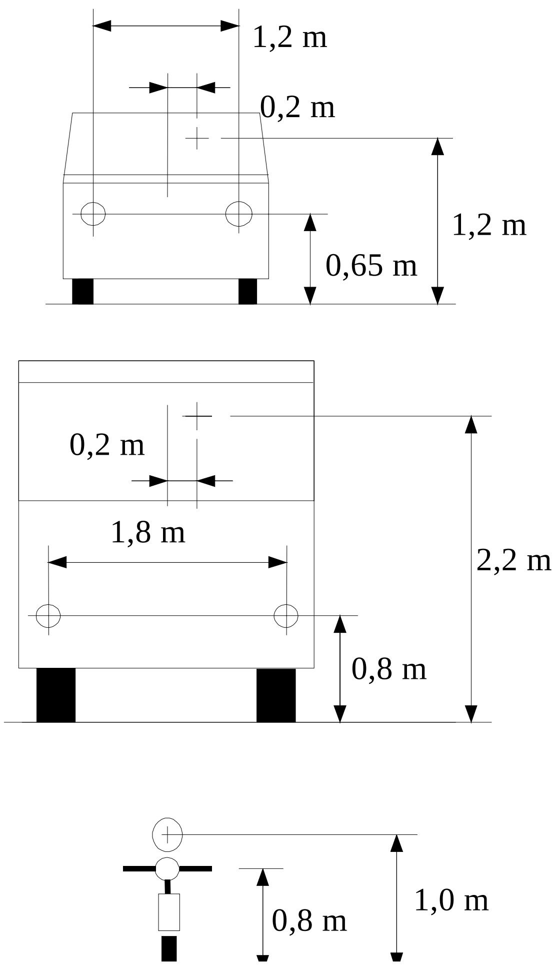
[7] For a straight and flat road, all of a longitudinal road marking will be inside the field of view from some distance ahead of the driver and onwards. On curving roads, the road marking may leave the field of view at some distance.

Table A4.1 - Factors AF1 and AF2 for the influence of age.

Age	20	30	40	50	60	70	80
AF1	1,00	1,10	1,20	1,41	1,69	2,93	8,81
AF2	1,00	1,02	1,14	1,38	1,75	2,25	2,86

The programme further has options for right-hand or left-hand driving. In either case, options for the vehicle are a passenger car, a bus/lorry or a motorcycle.

The option of right-hand driving leads to internal setting of the geometrical data shown in figure A4.2. For left-hand driving, the same data are set, except that the driver is shifted to the right of the passenger car and the lorry.



Passenger car with two headlamps placed
2 m in front of the driver.

Bus/lorry with two headlamps placed 0,95 m in front of the driver.

Motorcycle with one headlamp placed 0,5 m in front of the driver.

Figure A4.2 - Geometry of vehicles.

The options of right- or left-hand driving, which have a further effect on the intensity distribution of the low beam headlamp, are also considered (see section "headlamp illumination and coefficients of retroreflected luminance R_L").

The dimensions of figure A4.2 are meant to represent typical vehicles; they are taken from a document produced by CEN/TC 226 'Road equipment' WG3 'Vertical signs' relating to the luminance of vertical road signs.

Glare is introduced directly by indication of a value of a veiling luminance L_v ($cd \cdot m^{-2}$). The value should be indicated for a twenty year old driver, as the programme converts to the actual driver age by multiplication with the above-mentioned factor AF2.

Glare occurs in particular at night, mainly caused by headlamps of opposing vehicles.

When meeting one or more vehicles on a straight road, the veiling luminance is roughly constant for a long range of meeting distance. Typical values are given in table A4.2 for the assumption that the driver looks straight ahead and that opposing vehicles use the low beam with an intensity of 200 cd for each headlamp.

The driver may avoid some of the glare by fixing his gaze at a location away from the oncoming vehicles, for instance at the edge line. However, the driver has to sustain more glare if he looks at a location closer to the oncoming vehicles, for instance at the centre line.

When the road curves, the veiling luminance depends on all the geometrical details of the situation and is as likely to be higher as it is to be lower than the values in table A4.2.

Table A4.2 - Veiling luminance L_v in $cd \cdot m^{-2}$ by glare from oncoming vehicles on a straight road.

number of on-coming vehicles:	lateral separation to oncoming vehicles: 3,5 m	7,0 m	10,5 m	14,0 m	17,5 m
1	0,098	0,024	0,011	0,006	0,004
2	0,196	0,049	0,022	0,012	0,008
3	0,294	0,073	0,033	0,018	0,012
4	0,392	0,098	0,044	0,024	0,016
5	0,490	0,122	0,054	0,031	0,020

An additional veiling luminance, leading to effects similar to glare, is caused by scattering in a dirty, wet or worn wind screen. Resulting veiling luminances can become as large as those indicated in table A4.2.

Daylight/road lighting may also cause glare. Extreme glare is experienced in daylight, when driving against a low sun. Such situations are outside the scope of the programme.

Road lighting installations for traffic routes are mostly designed so that the veiling luminance is limited to about 15% of the road surface luminance. This means that the veiling luminance[8] of road lighting is often in the range of 0,08 to 0,3 $cd \cdot m^{-2}$.

[8] Requirements for glare limitation in road lighting are mostly expressed in terms of an effect of glare called the Threshold Increment TI. Values of TI may, however, to some approximation be converted to values of the veiling luminance.

A4.3 Road geometry

The programme operates with a single road marking. The input includes options for position of the road marking to the right or the left of the vehicle. Additional input is the tranverse distance from the centre of the vehicle to the centre of the line.

The road can be made to curve horizontally and/or vertically as indicated in figure A4.3 and as explained below.

The input includes options for a straight road, or a road curving to the right or the left. For curving roads, additional input is the curve radius R_h (m). Values below 100 m are not accepted.

The curve radius applies for the path of the vehicle. The curve radius of the road marking is smaller when the road marking is at the inside of the curve, and larger when it is at the outside. The difference between the two radii is the above-mentioned transverse distance from the vehicle to the road marking.

The input further includes options for a flat road, or a road curving upwards or downwards. For curving roads, additional input is the curve radius R_v (m). Values below 100 m are not accepted.

If the road has both a horizontal and a vertical curve, the path of the vehicle will be in a vertical cylinder defined by the horizontal curve, and will follow the vertical curve within this cylinder. The plane of the road at some location in the path is defined by a horizontal line perpendicular to the path at that location.

The calculated visibility distance is measured along the path of the vehicle, starting at the position of the driver and ending at the point next to the particular location, where the road marking is visible. Accordingly, the driver has to drive a distance equal to the visibility distance to arrive at that location.

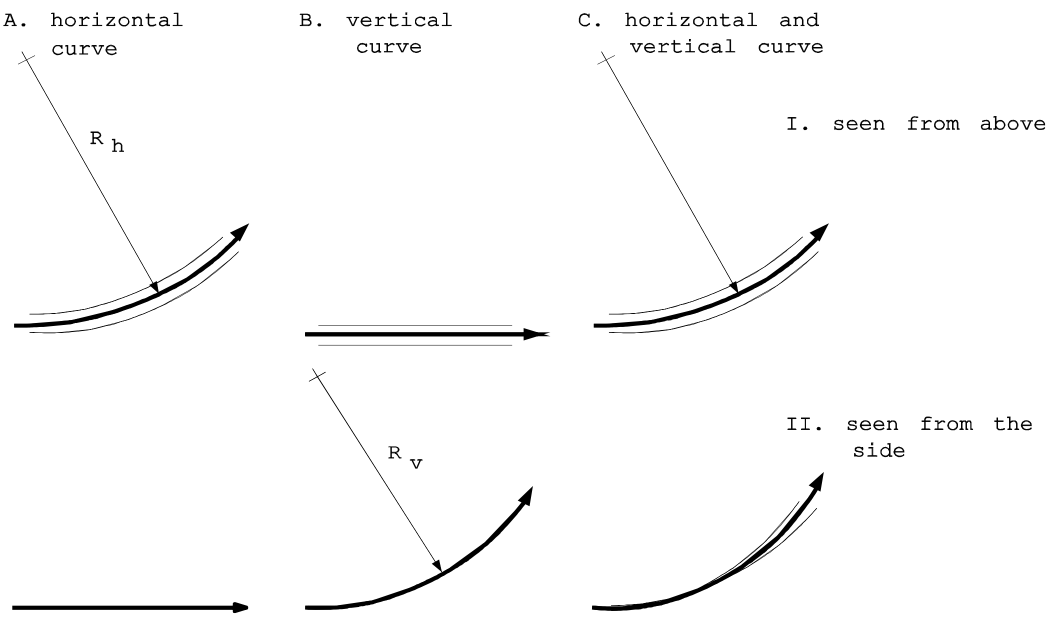


Figure A4.3 - Illustration of horizontal and vertical curve.

A4.4 Headlamp illumination and coefficients of retroreflected luminance R_L

The input includes options for headlamp(s) off, on low beam or on full beam. For headlamp(s) on, the input includes a factor for the headlamp luminous intensity, and values for the coefficients of retroreflected luminance R_L for the road marking and the road surface.

The option of the low beam makes the programme use the intensity distribution shown in figure A4.4, having a feature of a cut-off defined by a horizontal line to the left and an inclined line to the right representing the elevated part of the beam.

This is for the option of right-hand traffic. For the option of left-hand traffic, the inclined line and the elevated part of the beam is to the left (right and left are interchanged).

The intensity distribution has constant intensity in three zones:

- **10.000 cd** in directions below the cut-off;
- **1.000 cd** in directions between the cut-off and the horizontal;
- **200 cd** in directions above the horizontal;
- **0 cd** in directions outside ±10° to the sides and ±5° up/down.

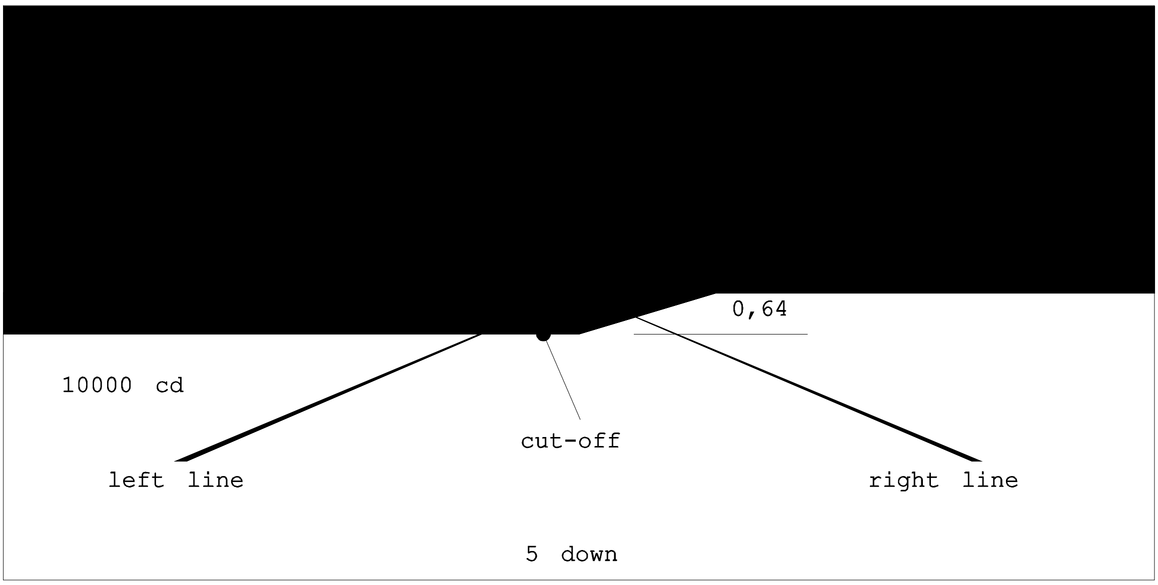


Figure A4.4 - Intensity distribution of the low beam (shown for right-hand traffic).

The option of the high beam makes the programme use a constant intensity of 10.000 cd in directions inside the zone of ±10° to the sides and ±5° up/down. The intensity is zero (0 cd) for directions outside this zone (not shown).

For either option, the intensities are multiplied internally by the factor value before being used in calculations.

Both of these distributions are obviously simplified as compared to real headlamp distributions of varying intensity. The simplification serves to avoid the complexity of choosing between many different types of real headlamps. The simplification may to some extent be justified by the fact that precise details of the distribution are not important[9].

The distributions may be considered to represent a new and fairly powerful headlamp. For worn or dirty headlamps, the factor should be set to a value much less than unity.

Values of R_L for the road marking and the road surface are to be input for the standard measuring geometry of EN 1436 and in the unit of $mcd \cdot m^{-2} \cdot lx^{-1}$.

For the dry condition, EN 1436 provides classes of R_L minimum 100, 200 and 300 $mcd \cdot m^{-2} \cdot lx^{-1}$ for white road markings and minimum 80, 150 and 200 $mcd \cdot m^{-2} \cdot lx^{-1}$ for yellow road markings.

Newly applied road markings often have R_L values in excess of these values, but the value decreases during functional life. The value of minimum 100 $mcd \cdot m^{-2} \cdot lx^{-1}$ is the one most often applied for white road markings.

Road surfaces in the dry condition have R_L values in the range from 5 to 30 $mcd \cdot m^{-2} \cdot lx^{-1}$. The lower end of the range applies for asphaltic road surfaces with dark stone aggregates, while the upper end of the range applies for asphaltic road surfaces with lighter stone aggregates and cement concrete surfaces.

For most road markings in conditions during rain or wetness, the R_L drops to very low values. Road markings with a strong surface texture, like profiled road markings, or with other means to achieve the same purpose, maintain some retroreflectivity during rain or wetness. For such road markings, EN 1436 provides classes of R_L minimum 25, 35 and 50 $mcd \cdot m^{-2} \cdot lx^{-1}$.

For road surfaces in conditions during rain or wetness, the R_L drops to low values of typically 0 to 10 $mcd \cdot m^{-2} \cdot lx^{-1}$.

The standard geometry specified in EN 1436 applies for a simplified passenger car and a distance of 30 m to the road marking, while the actual geometrical situations occurring in the calculations are more variable.

The most important source of variation of the R_L value is proportionality to the ratio of $\sin\varepsilon/\sin\alpha$, where ε and α are angles of illumination and observation, both measured to the plane of the road surface.

The programme takes this source of variation into account by internal calculation of the correct value of the ratio in all cases. For a discussion of other sources of variation, please refer to chapter 5.

The option bus/lorry leads to a relatively low luminance of a road marking (the drivers sits high, making $\sin\alpha$ relatively large and the ratio $\sin\varepsilon/\sin\alpha$ relatively small), but simultaneously to a relatively large apparent area (in proportion to $\sin\alpha$). Therefore, the option of a bus/lorry does not necessarily lead to substantially shorter visibility distances than the other optional vehicles.

[9] The visibility of a longitudinal road marking depends on the luminance and contrast over some length of the marking, and therefore on the illumination over some length rather than at a single point.

A4.5 Daylight/road lighting and luminance coefficient in diffuse illumination Qd

The input includes a value of illuminance in diffuse illumination. If positive, additional input are values for the luminance coefficient in diffuse illumination Qd for the road marking and the road surface.

Diffuse illumination is an approximation to the daylight illumination in cloudy conditions, and to road lighting as an average for different locations on the road surface.

Daylight in cloudy weather is to levels of more than 10.000 lx in full daylight, and perhaps to 1.000 lx in weak daylight such as in wintertime in Nordic countries. In twilight, the level may be 100 lx down to zero.

Road lighting[10] for traffic routes generally produces illuminance levels of about 7 to 30 lx, while road lighting for domestic roads typically produces lower levels, say 1 to 5 lx.

Qd values are to be input for the standard measuring geometry specified in EN 1436 and in the unit of $mcd \cdot m^{-2} \cdot lx^{-1}$.

For the dry condition, EN 1436 provides classes of Qd minimum 100, 130 and 160 $mcd \cdot m^{-2} \cdot lx^{-1}$ for white road markings and minimum 80 and 100 $mcd \cdot m^{-2} \cdot lx^{-1}$ for yellow road markings.

Newly applied road markings often have Qd values in excess of these values, and in fact sometimes close to a theoretical maximum of approximately 300 $mcd \cdot m^{-2} \cdot lx^{-1}$. However, the value decreases during functional life.

Road surfaces in the dry condition have Qd values in the range from 50 to 100 $mcd \cdot m^{-2} \cdot lx^{-1}$, or even higher. The lower end of the range applies for asphaltic road surfaces with dark stone aggre-gates, while the upper end of the range applies for asphaltic road surfaces with lighter stone aggregates and cement concrete surfaces.

The standard geometry of EN 1436 applies for a simplified passenger car and a distance of 30 m to the road marking. However, the Qd value does not change much with the geometrical conditions and the programme uses the input value directly for calculations.

[10] Road lighting for traffic routes is usually designed to produce a selected road surface luminance in the range of 0,5 to 2 $cd \cdot m^{-2}$. The above-mentioned illuminance values correspond roughly to such luminance levels.

Appendix 5 - COST 331 CD-ROM

On the COST 331 CD-ROM contained in this report you will find the following items:

– The VISIBILITY computer programme
– Additional reports in PDF format
– Video records of the trials undertaken in the course of this work

System requirements

– Windows 95, 98 or NT
– Internet Explorer 3.0 or higher
– Netscape 4.0 or higher
– QuickTime 4 if you are using Internet Explorer
– QuickTime 3 if you are using Netscape
– Adobe Acrobat Reader

How to install this CD-ROM

Simply, insert the CD-ROM into the CD-ROM drive. The setup wizard will then guide you through the installation.

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From July 1995 to April 1999, fifteen European countries developed the Action COST 331 with the main objective of establishing a validated scientific method with which, on the basis of drivers' visual needs, the optimum pavement marking design ensuring visibility by day and by night, in all weather conditions, can be determined.

The project, confined to longitudinal road markings on interurban roads, was subdivided in the following research programme:

– A complete review of the state of the art by means of a literature survey and a questionnaire answered by 15 European countries.
– An investigation of the visibility distance of road markings, in a field driving experiment involving a number of test persons and variable conditions (concerning road marking pattern and reflectivity, and headlamp intensity).
– An investigation of the driver need for visibility distance, carried out in a driving simulator, involving a number of test persons and variable conditions concerning driving speed, visibility distance and road curvature.
– Monitoring driver behaviour in real traffic conditions throughout different road sections in Finland, Portugal and Switzerland (built up with different designs and quality of road markings), by using an unobtrusive instrumented car and involving a statistically selected number of test persons.

The conclusions of COST 331 show that there is a need to establish a national policy for road marking design, due to their influence on road safety. To do that, the scientific basis provided in COST 331 can fruitfully be used. Nevertheless, COST 331 does not provide answers to all the questions which may be asked in connection with road markings but has taken a big step forward in establishing better knowledge of the driver's visual needs and the capability of road markings to provide that needed visual information. COST 331, in this sense, provides an outstanding scientific background for future research in this field and for the revision of road marking standards.