# The effect of altered road markings on speed and lateral position

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A meta-analysis

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# Summary


The basic principle of a sustainably safe traffic environment is that the traffic system is maximally tuned to the capabilities and limitations of its users. The road network and road infrastructure are easy to understand and predictable, and more or less automatically elicit the required, safe behaviour. However, we only have some general ideas about what such an infrastructure should look like, and these ideas are hardly based on empirical evidence. Research has shown that marking is the most important road characteristic with respect to the recognition of the road types that are used in a sustainably safe traffic system, and hence to the speed at which one is permitted to drive on these types of roads. But that does not tell us what effects on speed are to be expected when we replace the current road markings by other markings.

What we do know about the relationship between road design and road user behaviour, is often based on the results of small-scaled studies. For example, a group of researchers has used a before-and-after study to investigate the effect on the average driving speed of adding an edge line. On the basis of such small-scaled studies, it is often difficult to predict general effects. Such effects can only be deduced by performing a systematic literature review such as a meta-analysis.

In this report, we describe the results of a meta-analysis on the effects of altered road markings on the speed and lateral position of motor vehicles. Several kinds of alterations were studied, such as applying an edge line to a previously unmarked road or to a road that was already marked with a centre line. First, we studied the general effects of these different kinds of road markings. Next, we focused on those alterations that correspond to replacing the current road markings in the Netherlands by the markings proposed for the three sustainably safe road categories (through roads, distributor roads and access roads).

As far as the general effects of altered road markings are concerned, the results of this meta-analysis showed that adding an edge line or a centre line to a road that was previously unmarked leads to an increase in the speed driven and a shift of the lateral position towards the edge of the road. Both effects have been related to negative effects on road safety, the first one based on more evidence (Finch et al., 1994; Aarts, 2004) than the second one (Mäkinen et al., 1999). The actual effects on road safety are, however, not known, since accident data were not included in the studies on which this meta-analysis was based.

With respect to the alteration of road markings as part of the implementation of a sustainably safe traffic system, this meta-analysis shows that up till now, very little research has been done on the effects of these alterations on road user behaviour. The only sustainably safe road type for which enough data was available, was the access road. The results of the experiments that have studied alterations in road markings that were relevant for this type of road, point into the direction of a small decrease (-2 kilometres per hour) of the mean speed driven.

# Contents

# Foreword

This study was carried out as part of the SWOV research theme 'Road users: the relationship between behaviour, surroundings and accidents'. The aim of this research theme was to gain a better founded insight in the extent to and way in which road user behaviour is being influenced by characteristics of the environment (the road and its immediate surroundings) and other road users' behaviour, and to what extent this road user behaviour contributes to accident causation. Specific questions that directed the research in this SWOV research theme are:

- Which characteristics of the environment and which behaviour of others determine the actual behaviour of road users and to what extent can the desired or correct behaviour be induced or disrupted by the environment?
- To what extent can the physical and/or emotional condition of the road user influence his/her behaviour in traffic (in relationship to characteristics of the environment and other road users)?
- What is the relationship between road user behaviour and accident causation?

The present study – called 'the relationship between characteristics of the environment and road user behaviour; a meta-analysis' - relates to the first question. The aim of this study is to gain insight in the effect of the environment on road user behaviour. We emphasize the fact that this study can only make *a contribution* to this insight, since the number of characteristics of the environment and the number of types of road user behaviour are both numerous. Our contribution will be limited to a meta-analysis on the relationship between one characteristic of the environment and one type of road user behaviour. This report describes the results of this meta-analysis. An earlier report (Davidse & Van Driel, 2002) gives a full account of the decisions made in the preliminary phase of this project, such as those regarding the selection of the relationship that was to be studied in the meta-analysis (which characteristic(s) of the environment and what type of road user behaviour), the selection of studies that investigated this relationship, and the procedure we used to code these studies. The coding sheet is also included in the above-mentioned report.

# 1. Introduction

## 1.1. Scope of this study

In the Netherlands, road safety policy is to a large extent influenced by the concept of a sustainably safe road traffic system. This concept was introduced in the early nineties with the aim to give a new impulse to road safety. The objective of Sustainable Safety is to have a traffic system in which the chance of an accident is very limited. When an accident cannot be prevented, the chance of serious injury is virtually excluded (see Koornstra et al. (1992); Van Schagen & Janssen (2000) for an elaborate description of the sustainably safe road traffic system).

The main emphasis of Sustainable Safety is on the road users and their behaviour: all relevant characteristics of infrastructure, vehicle and traffic regulations should be maximally tuned to the capabilities and limitations of road users. Although the relationship between road design and road user behaviour has been studied in various ways, our knowledge about this relationship is still limited.

The relationship between road design and road user behaviour is mostly investigated by means of small-scaled studies. The road environment is adjusted (for instance by adding edge lines) and a certain aspect of road behaviour (for example speed) is measured, both before and after the alteration of the environment. It is often difficult to predict general effects on the basis of a single small-scale study. The study results depend on the circumstances under which the experiments took place (e.g. which road type, average daily traffic, road environment) and the results of a single study usually do not give any insights into the range of possible effects, nor into variables that can influence the magnitude of the effect. In fact, general conclusions on the effects of road design alterations can only be drawn from reviews. However, reviews on the relationship between road characteristics and road user behaviour are hardly available. The available reviews (e.g. Noordzij, 1996; Martens, Comte & Kaptein, 1997; Rumar & Marsh II, 1998) summarize existing studies, but the authors do not deduce general effects or moderating variables. Therefore, there is hardly any valid empirical evidence which can tell us how the principles of a sustainably safe road traffic system should be translated into specific design requirements and recommendations (Van Schagen & Hagenzieker, 2000).
This report describes the results of a research project which aims to contribute to the knowledge of the interaction between road environment and road user behaviour by means of a meta-analysis.

## 1.2. The method of meta-analysis

In brief, a meta-analysis can be described as a secondary analysis of study results. Studies with a similar research objective become the observations in a statistical analysis in which the mean effect, its variation and the variables that can explain this variation, are determined. The method of meta-analysis can also be described as a quantitative type of literature review (see Mullen [1989] for a discussion on the differences between the traditional narrative literature review and the meta-analytic review). Sometimes the criticism is heard that by using meta-analysis, one is comparing apples and oranges. Glass (1978; cited in Rosenthal [1991]) very adequately counters this criticism by saying: “if we are willing to generalize over subjects within studies, why should we not be willing to generalize over studies? If subjects behave very differently within studies we block on subject characteristics to help us understand why. If studies yield very different results from each other, we block on study characteristics to help us understand why.” (Rosenthal, 1991: p. 129). But of course, one has to be specific when formulating the objective of the meta-analysis and the dependent and independent variables should be defined accordingly, just as it should be done in primary studies. That is, one should think about the generalizations that make sense. Or as Hall et al. (1994) put it: “Combining apples and oranges to understand something about fruit may make more sense than combining fruits and humans to understand something about organic matter.” The level of generalization should be appropriate to the question being asked and should be scientifically useful. The synthesist must ask "Does this level of generalization add to our explanation and understanding of a phenomenon" (Hall et al., 1994: p.20).

## 1.3. The objective of this meta-analysis

Returning to the topic of our meta-analysis, the foregoing means that a choice had to be made on which specific relationship was to be studied. For that reason, the first part of our project consisted of a rough inventory of publications reporting an effect study on the relationship between a road characteristic and an aspect of road user behaviour. This inventory led to a matrix of relationships which shows that an important part of the studies is aimed at the relationship between road design and speed (e.g. Botterill & Thoresen, 1996; Brenac, 1989; McLean, 1981). Some of those studies also investigated the relationship between road design and some other aspect of road behaviour, for instance overtaking behaviour (e.g. Carlsson & Lundkvist, 1992), lateral position (e.g. Triggs & Wisdom, 1979; Steyvers & De Waard, 2000) or the interaction with other road users (e.g. Dijker, Bovy & Vermijs, 1997). The aspect of road design that has been studied the most in the above-mentioned studies is the cross section. Other aspects of the road design that have been studied much are horizontal alignment and road marking (the complete matrix is included in Davidse & Van Driel [2002]).

The relationship between road markings and speed was chosen as the subject of our meta-analysis. This selection was made on the basis of several criteria, among which the relevance for road safety research, especially for the concept of Sustainable Safety, and the number of available studies. Research has shown that marking is the most important road characteristic with respect to the recognition of the road types that are used in a sustainably safe road traffic system, and hence to the speed at which one is permitted to drive on these types of roads (Janssen, Claessens & Muermans, 1999; Van Schagen et al., 1998). According to the matrix of studies mentioned above, almost all of the studies that examined the effects of road markings on road user behaviour, looked at the effects of markings on speed. We therefore decided to choose this relationship as the subject of our meta-analysis. Since many of the studies that investigated the effects of road markings on speed also paid attention to the relationship between road markings and lateral position, this aspect of road user behaviour is also included in the present meta-analysis.

The aim of the present meta-analysis is thus to determine the effect of different kinds of road markings on the speed of motor vehicles and their lateral position. Furthermore, it has been attempted to identify moderating variables that are related to the magnitude of these effects. To this end, a large number of study characteristics, which were selected on the basis of previous empirical findings or theoretical considerations, have been coded for our selection of studies. After an analysis of the general effects of different kinds of road markings, we focused on the specific markings that are related to sustainably safe road categories. *Paragraph 1.4* provides more details on these particular road markings and describes the principles of a sustainably safe traffic system.
The road markings studied in this report are confined to longitudinal lines at the centre or the edge of the pavement. The material used for delineation is restricted to paint (all types) and raised pavement markers (RPMs), also called road studs. Studies that examined specific markings for work zones were not included, neither were those that examined markings on ramps or entry/exit lanes. With respect to the measured speed and lateral position of motor vehicles, only those measurements were included that were obtained in unrestricted conditions (i.e. no instructions on speed to travel or lateral position were given other than already existing posted speed limits).

## 1.4. A sustainably safe traffic system: from theory to practice

A sustainably safe traffic system is based upon three key safety principles: functionality, homogeneity and predictability. *Functionality* refers to the use of the road network. The road network has to consist of a small number of road types or road categories with each category having its own and exclusive function with its own and exclusive requirements regarding use and behaviour (Van Schagen & Janssen, 2000). In the Dutch sustainably safe traffic system three types of roads are distinguished: access roads, distributor roads and through roads. Each type of road has a different function in the road network: through roads have a flow function for long distance travel at high speeds and, generally, for high volumes; distributor roads serve districts and regions containing scattered destinations; and the main function of access roads is to enable direct access to properties alongside a road or street. Through roads can only be found outside urban areas and correspond to the current motorways and trunk roads. Distributor roads and access roads are found both inside and outside urban areas.
According to the principle of *predictability*, road users should be able to recognize the function of the road they are driving on; when they know its function, they know what other types of road users and type of behaviour they may expect and how they themselves should behave (Van Schagen & Janssen, 2000). With that in mind, the authors of the document on 'Essential characteristics for the recognizability of roads in a sustainably safe road network' (Traffic Test, 2003) further developed the original idea of CROW to use different road markings for different types of roads (CROW, 1997). For roads outside urban areas, they proposed the following markings: through roads should have double continuous centre lines with green paint between them (or a median or a guard rail) and continuous edge lines; distributor roads should have double continuous centre lines (or a median) and broken edge lines; and access roads should only have broken edge lines (see the upper photographs in *Figure 1.1*). For roads inside urban areas, they suggested that distributor roads should have double continuous centre lines

| | Through roads | Distributor roads | Access roads |
|---|---|---|---|
| Outside urban areas |  |  |  |
| Inside urban areas | |  |  |

Figure 1.1. *Proposed road markings for through roads, distributor roads and access roads outside urban areas (upper line) and inside urban areas (bottom line) (Source: Traffic Test, 2003). Only painted markings are shown. Most through roads have guard rails or medians to separate lanes for opposing traffic. It is not intended to trade these physical barriers in for painted markings.*

(or a median) and broken edge lines (or kerbs) and that access roads should have neither centre nor edge lines (see the bottom line of *Figure 1.1*). Currently most of the roads have other markings than those specified above, and therefore the road markings on these roads will have to be altered (all parties concerned accepted the proposed markings on the 11th of December 2003). The alterations needed for roads outside urban areas are shown in *Figure 1.2*. From a road safety perspective, an interesting question then is: “What will be the effect of these alterations on the speed and lateral position of road users?”.

On the basis of the principle of *homogeneity*, which states that large differences between road users in speed, mass and direction should be prevented, it is preferable that the alterations of the road markings do not lead to an increase of the variation in speed between road users. From general road safety considerations, an increase in the mean speed would also not be appreciated; it is generally agreed upon that an increase of the average speed leads to an increase in the chance of having an accident (Aarts, 2004; Finch et al., 1994).
The road safety consequences of changes in the lateral position of road users (e.g. as a result of altered road markings) are less clear. A shift of the lateral position towards the edge of the road might reduce the number of frontal collisions. But at the same time, a shift of the lateral position towards the centre of the road might reduce the number of run-off-the-road accidents. It could be argued that the first effect on accidents will probably only be relevant for roads without any physical barrier between lanes for traffic in opposing directions (or restriction on overtaking). Run-off-the-road accidents can happen on all roads, although the probability will differ depending on the position of the edge line. Taking the example of the sustainably safe road types, the edge line on through roads and distributor roads is situated 30 centimetres from the edge of the carriageway, while on

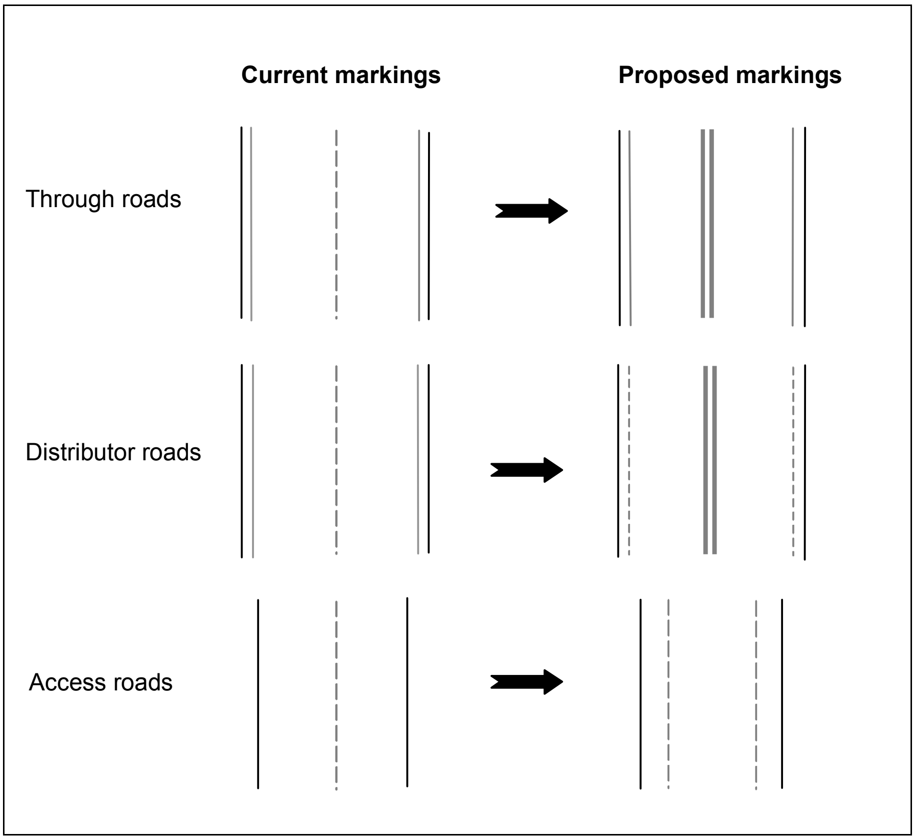


Figure 1.2. *Differences between current and proposed markings for roads outside urban areas per road type.*

access roads this distance is at least 50 centimetres (but generally 1.25 metre). The risk of running-of-the-road will therefore be smaller on access roads than on the other two road types.
A lateral position that is closer to the edge of the road may also have adverse effects on the safety of cyclists driving on the right side of the road. In the Netherlands, cyclists are only allowed on the carriageway of access roads. So even on access roads, a shift towards the edge of the road may have negative effects on road safety.
All in all it seems probable that a lateral position of the vehicle which is closer to the centre of the road, is safer than a lateral position that is closer to the edge of the road. However, the actual effects may vary per road type and country (presence of a physical barrier and/or cyclists). Mäkinen et al. (1999) came to the same conclusions, based on a rough comparison of the number and severity of accidents in which a car crossed the centre line versus accidents in which a car crossed the edge line: run-off-the-road-accidents seem to occur more often than frontal collisions, and they lead to injuries that are more severe.

## 1.5. What we already know about the effects of markings on speed and lateral position

Earlier narrative reviews of the literature on the effects of road markings on speed and lateral position (e.g. Hall, 1979; Steyvers,1994; Rumar & Marsh II, 1998) have reported that the effects found in different studies are inconsistent. The inconsistency of these results could be the result of a number of factors that may affect lateral position and interact with the effects of road markings. These factors include time of day, weather, road width and geometry, traffic parameters and the presence of other road markings (Hall, 1979).

Rumar & Marsh II (1998) looked into the effects of the width of edge lines. In general, line width has an effect on driver behaviour. Specifically, the lateral distance from the edge of the road tends to be positively correlated with line width. In other words, as the width of the edge line increases, so does the distance from that line. Besides that, line width also has an effect on lane-marking visibility, which in turn may affect speed. Several studies by Zwahlen and colleagues (cited in Rumar & Marsh II, 1998) have shown that the main factor that influences visibility is the amount of retroreflective material. Since wider lines contain more retroreflective material, they are detected earlier. Whether the wider line is accomplished with one wide line or two narrow lines is not important, according to the studies by Zwahlen and colleagues. Neither did they find an effect of the lateral separation distance between double lines. The same studies by Zwahlen and colleagues also showed that continuous lines are detected significantly earlier than broken lines. The differences ranged from 10 to 50%, with wider lines increasing the differences (Rumar & Marsh II, 1998).
If the objective is not visibility but speed reduction, broken lines have advantages over continuous lines. Because of their visibility characteristics, continuous lines lead to a better visual guidance. If the lane markings are so effective that they considerably reduce the mental load and attention required to follow the road, drivers may react by increasing their speed. Broken lines, on the other hand, provide less visual guidance but a better impression of the speed driven (Van der Hoeven, 1987; Steyvers, 1994; Claassen & Pouwels, 1998; Rumar & Marsh II, 1998).

With respect to time of day, all reviews report that road guidance is drastically worse at night. Rain and wet roads further increase the nighttime difficulties (Riemersma, 1986; Rumar & Marsh II, 1998). Drivers are especially dependent on lane markings during such adverse and degraded conditions. It is precisely in these circumstances that regular road markings fail. Other types of road markings, such as raised-rib road markings, retroreflective paint and the addition of raised pavement markers could improve route guidance (Riemersma, 1986). But the improved visual guidance could also lead to driving speeds that are too high given the driver's visual recognition and detection abilities (Leibowitz and colleagues; cited in Rumar & Marsh II, 1998).

The above findings show that a balance should be found between the visual guidance provided by road markings (leading to positive effects on lateral position and reducing the risk of running-off-the-road) and the undesirable effects on speed (when the road becomes easier to follow the driving speed will increase). Or as Rumar & Marsh II (1998) put it, a compromise should be found between two widely separate views on enhancing road guidance: "The traditional and established one states that more information about the road ahead results in smoother and safer driver behaviour. The other view states that drivers' visual guidance is already better than drivers' recognition, and visual guidance should not be further enhanced because that may lead to higher speeds and overconfidence" (Rumar & Marsh II, 1998: p. 10). These higher speeds are especially unwanted on roads that do not have a flow function, such as access roads (Schreuder & Schoon, 1990).

# 2. Method

## 2.1. Selection of studies

In accordance with our definition of road markings (and the aim of this study), a literature search was performed using the International Transport Research Database (ITRD), the SWOV library, databases of related research institutes, reference lists from articles, and suggestions of colleagues. The keywords that were used for searching the databases were *carriageway** or *road** in combination with *marking** or *marker** and *speed**, *steering**, *driving** or *behavio**. There was no restriction on the year of publication, nor on the publication form. The studies were gathered until the beginning of June 2001, with the intention of including all earlier, relevant studies. A total of 152 publications were found. Those publications were subsequently screened on their suitability. Studies were excluded from the analysis when:

- markings turned out to be special work zone markings, chevrons or transverse markings;
- the markings were not made of paint or raised pavement markers (RPMs), but for instance consisted of post mounted delineators (PMDs);
- markings consisted of painted speed limits;
- experiments solely took place on ramps;
- no information was provided on speed or lateral position;
- the relationship between road markings and road user behaviour was not the main subject of interest (e.g. road markings as a countermeasure for alcohol related accident types);
- statistical information was not given or was insufficient for further statistical analyses;
- there was no comparison made between situations (either before versus after or experimental versus control);
- the study turned out to be a review or a theoretical article/report.

After the publications that matched with one or more of the exclusion criteria were deselected, 41 publications were left (see *Appendix A1*). One publication can contain descriptions of several experiments, and one experiment can result in several comparisons between different types of road markings.

## 2.2. Study characteristics

A large number of variables, selected on the basis of previous empirical findings or theoretical considerations, were used to describe the characteristics of the experiments and comparisons. These variables can be grouped according to the type of information they give. The most important variables were:

*Background variables*
(1) year of the experiment, (2) country, (3) publication form, (4) road type, (5) type of road section (curve, straight or both), (6) speed limit, (7) road environment (open field, trees, buildings), (8) characteristics of the cross

section (width of pavement, lane and edge strip), (9) average daily traffic, (10) weather conditions.

*Research characteristics*
(1) research design, (2) observation method (simulator, instrumented vehicle, static observations), (3) sample size, (4) length of the experimental road section, (5) measurements at day or at night (light conditions), (6) possible influence of other road users (opposing traffic and drivers in the same lane) on the behaviour of the observed road users.

*Characteristics of the (alterations in type of) markings*
Various characteristics of the road markings were coded for both before and after the alteration. These characteristics included: (1) available lines (edge lines, centre line, both or none) (2) continuous or broken lines, (3) double or single lines, (4) Material used (painted markings, lines that consist of raised pavement markers (RPMs) or both) (5) width of the lines, (6) spacing of the lines and gaps of broken lines (or distance between RPMs), (7) distance between double lines.

*Information about the impact of the alterations and effect sizes*
Both before and after the alteration of the road markings, speed and lateral position were recorded. All lateral positions were recoded into lateral positions measured from the centre of the road using the coded values for lane width, pavement width and width of the centre line (based on the formulas used by Commandeur, Van Schagen & De Craen [2003]; see *Appendix B*). The effect of the alterations was calculated from changes in the mean speed (in km/h) and mean lateral position (in cm): after – before. If data was available from control sites on which the road markings remained unaltered, an extra (corrected) effect size was calculated by subtracting the effect observed in the control group from the effect in the experimental group: $(\text{after}_{EXP} – \text{before}_{EXP}) – (\text{after}_{CONTR} – \text{before}_{CONTR})$.
In case the standard deviation of speed and/or lateral position was reported, the standardized effect of the alterations was calculated by dividing the changes in the mean by the standard deviation in the period before alterations were made: $(\text{after} – \text{before})/\text{sd}_{\text{before}}$. Some of the experiments also reported the speeds and lateral positions measured some period of time after the road markings were altered. Those follow-up measurements were also recorded and long-term effects were calculated accordingly: follow-up - before.

In terms of road safety implications, the effect of altered road markings on the differences in speeds between drivers is at least as important as the effect on the mean speed driven. Therefore, the standard deviation was also used to calculate the effects the alterations had on the differences in speeds between drivers: $\text{sd(speed)}_{\text{after}} – \text{sd(speed)}_{\text{before}}$. The same was done for the differences in lateral position between drivers: $\text{sd(latpos)}_{\text{after}} – \text{sd(latpos)}_{\text{before}}$.

## 2.3. Coding procedure

Two coders independently coded each of the experiments (and each of the comparisons) on each of the variables. The advantage of double coding is that the reliability of the codings can be checked. A precondition for a comparison of the codings is that both coders code the same experiments and all comparisons that are reported within a publication. A meta-analysis carried out by Hagenzieker, Bijleveld & Davidse (1997) showed that it is difficult for coders to select all relevant experiments and all relevant comparisons that are reported within a publication. To avoid this problem, the experiments and comparisons that had to be coded were determined in advance. The list of experiments and comparisons was included in the set of coding instructions. Other elements of the coding instructions related to an explanation of the elements of a cross section, what to do in case of doubts about the value of one of the variables and formulas to convert values into standards (e.g. feet into metres, miles per hour into kilometres per hour). Depending on the quality of the codings - which was checked by a third independent person – it was decided either to use the dataset of one of the coders (in case the interrater reliability was very high) or to combine the datasets of the coders into one database. The latter option has the advantage of keeping the extra information that was provided by one of the coders and missed by the other. But it also has the disadvantage of inflating the sample size. This increases the probability of rejecting the null hypothesis or, stated differently, it increases the chance of finding an effect of altered road markings on speed or lateral position.

## 2.4. Types of analysis

After calculating basic statistics for the total dataset, a selection was made on the alterations of the road markings that were to be studied in more detail. This selection was based on the changes in road markings that are depicted in *Figure 1.2*, which will lead to road markings that are in accordance with the guidelines proposed in the document about "Essential characteristics for the recognizability of roads" *(§ 1.4)*. Having selected the alterations to be studied in detail, separate datasets were extracted from the total dataset, leading to a dataset for each of the road types distinguished in the sustainably safe traffic system: through roads, distributor roads and access roads. From that point on, the same analyses were carried out for all three datasets. First of all, we calculated the basic statistics of the experiments that studied the alterations of the respective road category. After that, the effects of the alterations were studied.

# 3. Results

The 41 publications that were selected (see *Appendix A1*), together described 201 comparisons between different types of road markings; an average of almost 5 comparisons per publication. The results of the analyses of these comparisons will be described separately for the total dataset and for the subsets that relate to the road markings needed on through roads, distributor roads and access roads.

## 3.1. Results for the total dataset

All 201 comparisons were coded by two coders. This resulted in two datasets. These datasets were compared to determine the influence of the coder on the values of each of the coded study characteristics. First of all, a third independent person compared the values of the effects coded by each of the coders. In case large differences were found between the values of the two coders, she decided on the correct value for the variable in question based on going back to the original publication. After corrections were made on the effect variables and any related variables (such as lane width and pavement width), association measures of matched records from the two coders were calculated.
Inspection of the raw data learned that for some comparisons the codings of the first coder were more complete, for some other experiments the situation was the other way round. To avoid losing the extra information provided by one of the coders, it was decided not to choose for one of the datasets, but to combine them and to add the variable ‘coder’. This resulted in a database with 402 coded comparisons. *Table 3.1* shows a summary of the study characteristics.

### 3.1.1. *Differences between the coders*

To test the conformity of the codings of the two coders, association measures were calculated for the categorical (Cramer’s V, CV) and continuous variables (Pearson correlation coefficient). These association measures were calculated after a third independent person had checked and corrected any differences between the values on the variables regarding the effects on speed and lateral position. It turned out that these differences had their origins in three types of inaccuracies: 1) the study results had to be read from a graph or chart, 2) one of the coders used the wrong formula for calculating the standard deviation of a group of observations, or 3) one of the coders inadvertently chose the wrong value. In case the difference between the coders' values was caused by the second or third type of inaccuracy, the third independent person was able to take this difference away by going back to the original publication. Differences between the coders' values that were caused by the first type of inaccuracy were not corrected by the third independent person, neither were differences on other variables than those related to the effect size.
Correspondence between coders as calculated on the corrected database was above 0.96 (either Pearson $r$ or CV) for all variables concerning speed and lateral position, for the characteristics of the markings (except for the length of the broken centre line: Pearson $r$=0.84), for the characteristics of the cross section (width of pavement, lane and edge strip) and for the

| **Variable and class** | **Frequency / Mean (categorical/contin.)** | **Percentage / Median (categorical/contin.)** |
|---|---|---|
| Background variables: | | |
| *Year of the experiment* | 1982 | 1987 |
| *Country* | | |
| Netherlands | 114 | 28.4% |
| United Kingdom | 48 | 11.9% |
| USA | 210 | 52.2% |
| Other (Australia, Austria, Finland, Germany, Sweden) | 30 | 7.5% |
| *Publication form* | | |
| Journal article | 52 | 12.9% |
| Report | 278 | 69.2% |
| Conf. Proceeding | 72 | 17.9% |
| *Road type* | | |
| Inside urban area | 16 | 4% |
| 4-lane divided (or higher) | 4 | 1% |
| 2-lane road | 6 | 1.5% |
| 1-lane road | 6 | 1.5% |
| Outside urban area | 386 | 96% |
| 4-lane divided (or higher) | 31 | 7.7% |
| 2-lane road | 305 | 75.9% |
| 1-lane road | 50 | 12.4% |
| *Speed limit* | | |
| 45 – 75 km/h | 46 | 11.4% |
| 80 – 90 km/h | 187 | 46.5% |
| 95 – 120 km/h | 44 | 11.0% |
| Unknown | 125 | 31.1% |
| Research characteristics: | | |
| *Research design* | | |
| Before vs after | 302 | 75.1% |
| Before vs after + control | 20 | 5.0% |
| Experimental vs control (on same road) | 26 | 6.5% |
| Experimental vs control (on different roads) | 54 | 13.4% |
| *Observation method* | | |
| Simulator | 72 | 17.9% |
| Instrumented vehicle | 54 | 13.4% |
| Static observations | 276 | 68.7% |
| *N. of baseline/control obs.* | 3,072 | 205 |
| *N. of experimental obs.* | 3,702 | 236 |
| Characteristics of the alterations: | | |
| *Alteration of road markings* | | |
| 1. no lines => centre line (cl) | 30 | 7.5% |
| 2. no lines => edge line (el) | 22 | 5.5% |
| 3. cl => cl + edge line | 87 | 21.6% |
| 4. cl => no cl + edge line | 22 | 5.5% |
| 5. cl+el => cl+'other type of el' | 86 | 21.4% |
| 6. cl+el => no cl+'other type of el' | 4 | 1.0% |
| 7. cl+el => 'other type of cl'+el | 44 | 10.9% |
| 8. cl+el => variation of both cl+el | 4 | 1.0% |
| 9. alterations involving RPMs | 56 | 13.9% |
| 10. other alteration | 46 | 11.4% |
| unknown | 1 | 0.2% |
| Effect sizes: | | |
| *Effect on speed (km/h)* | -0.08 | 0.00 |
| *Effect on lateral position (cm)* | -3.75 | -1.00 |

Table 3.1. *Summary of study characteristics.*

variables country (and state in case of U.S.) of study, year of experiment, publication form, observation method and number of observations (see *Appendix C*). Correspondence between coders was the lowest for variables concerning the possible influence of drivers that drove in the opposite direction, the standardized effect on lateral position, road environment and weather conditions (CV or Pearson *r* between 0.62 and 0.69). Except for the standardized effect on lateral position, these variables were often not explicitly mentioned in the publication, and the coders had to infer the desired information from the text.

### 3.1.2. *Background variables*

Most of the experiments were published in reports (69%) and were carried out in the United States (52%) or the Netherlands (28%). Experiments took place between 1949 and 2000 (median 1987). The experiments that were carried out in the United States all took place before 1992, whereas the experiments that were carried out in the Netherlands all took place from 1992 onward. Road markings were typically applied on roads outside urban areas (96%) with a speed limit of approximately 80 kilometres per hour (47%).

### 3.1.3. *Research characteristics*

The evaluation of the behavioural effects of road markings is mostly investigated by means of a before-and-after study, in which speed and/or lateral position are observed before changing the road markings and some time after the alteration (80%). These observations were all made on the same road, except when extra observations were made on a control road. This was only the case for 6% of the before-and-after studies. Other experiments evaluated the behavioural effects of different types of road markings by comparing the observed speed and/or lateral position on one road section with that on another. Those being sections of the same road (7%), for instance consecutive road sections, or road sections of two comparable roads (13%).
Experiments in which a driving simulator was used, were coded as a before-and-after study. This kind of observation method was, however, not frequently used (18%). In the majority of studies, data concerning speed and lateral position were gathered by observers or measuring devices located at the side of the road, which observed all passing vehicles (69%). The number of observations in both the baseline and experimental condition varied from less than 10 to over 100,000.

### 3.1.4. *Characteristics of the alterations*

In the baseline (or control) situation, roads were either unmarked (13%), marked with only centre lines (30%), only edge lines (1%), both centre lines and edge lines (49%), or raised pavement markers (either alone or combined with lines: 6%). In the experimental situation, those markings were altered by adding a centre line, adding an edge line or adding both, by changing the spacing or width of (one of) the lines, by replacing a centre line with an edge line or by adding or replacing raised pavement markers. The alterations that were studied most, consisted of the addition of an edge line to a road only having a centre line (22%) and the variation of the edge line of a road that was already marked with both a centre line and an edge line (21%).

### 3.1.5. *Effect sizes*

#### 3.1.5.1. Effects on speed

A total of 320 effect sizes were calculated for the effect of road markings on the speed of road users. In general, a lowering of the average driving speed, which corresponds with an effect size of less than zero, is regarded as an improvement of road safety. Both decreases and increases of the average speed were found, with a maximum decrease of –10.6 km/hour (Pyne et al., 1995; experiment 23) and a maximum increase of 10.6 km/hour (Steyvers, De Waard & Garmann, 1996; experiment 2). *Figure 3.1* shows a histogram of the effect sizes regarding speed. The mean effect was -0.08 km/hour, which is negligable (s.d.=3.31).

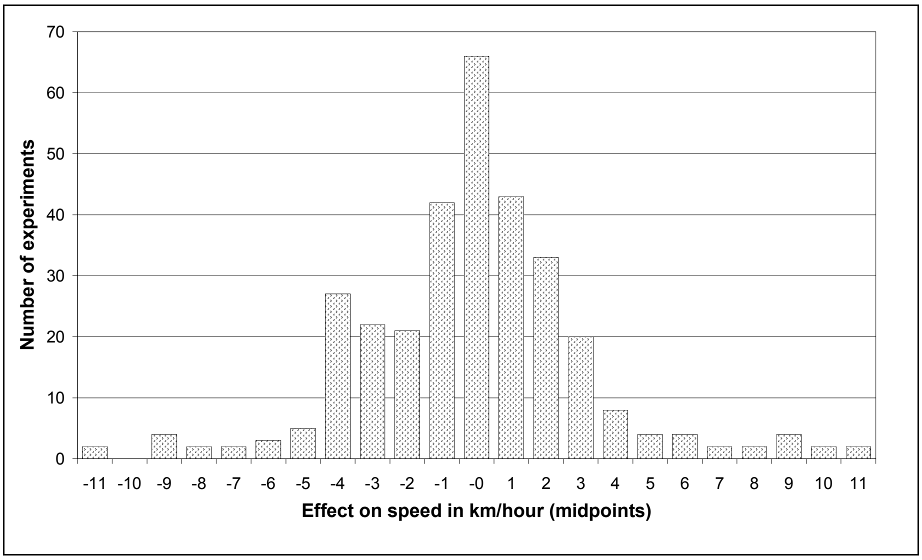


Figure 3.1. *Histogram of the effect on speed (in km/hour).*

Since the effect sizes vary from –10.6 to 10.6, it would be interesting to know whether characteristics of the experiments can explain this variation in effect sizes. In this paragraph, we will only look at the influence of the type of alteration of the road markings. The range of effect sizes found as a result of these alterations, and their mean and standard deviation are presented in *Table 3.2*. In the *paragraphs 3.3* to *3.5* more attention will be given to the influence of moderating variables (such as road type, speed limit, country of study) on the effects of changed road markings on speed.

The alteration that on average led to the largest increase in the mean speed driven, consists of adding an edge line to a road that did not have any road markings before (*Table 3.2*, type 2). Van Driel, Davidse & Van Maarseveen (2004) have further analysed the experiments that studied the effects of these alterations. None of the other variables included in the database seemed to have influenced the effect on mean speed. So the mere adding of an edge line to a road without any road markings leads to a significant increase of the mean speed ($p<0.001$). The same goes for adding a centre line to a previously unmarked road ($p<0.05$). These findings are in line with what was said in *§ 1.5* about visual guidance: providing the driver with some form of visual guidance can lead to increased driving speeds.

| Type of alteration | | N[1] | Range | | Mean | Standard deviation |
|---|---|---|---|---|---|---|
| | | | min | max | | |
| 1. | no lines => centre line (cl) | 14 | -1.9 | 9.6 | 3.0 | 4.6 |
| 2. | no lines => edge line (el) | 12 | 1.2 | 10.6 | 6.1 | 3.5 |
| 3. | cl => cl + edge line | 56 | -5.0 | 8.1 | 0.4 | 2.7 |
| 4. | cl => no cl + edge line | 14 | -4.0 | 1.0 | -1.7 | 1.7 |
| 5. | cl+el => cl+'other type of el' | 86 | -9.3 | 6.5 | -0.7 | 3.0 |
| 6. | cl+el => no cl+'other type of el' | 4 | 0.0 | 1.2 | 0.7 | 0.6 |
| 7. | cl+el => 'other type of cl'+el | 32 | -4.4 | 4.4 | -0.1 | 2.8 |
| 8. | cl+el => variation of both cl+el | 4 | -0.8 | 0.0 | -0.4 | 0.5 |
| 9. | alterations involving RPMs | 56 | -4.1 | 5.1 | 0.6 | 2.3 |
| 10. | other alteration | 42 | -10.6 | 2.4 | -2.5 | 3.3 |

[1]Since not all experiments have studied the effect on speed, the number of effect sizes can differ from the number of experiments reported in *Table 3.1*.

Table 3.2. *Effects on speed of different types of alterations of road markings*.

Van Driel et al. (2004) have also analysed the data regarding the two other alterations concerning the addition of an edge line (either to a road that was already marked with a centre line (*Table 3.2*, type 3) or as replacement of a centre line (type 4)). Both their effects were significantly different from the effect of adding an edge line to a previously unmarked road ($p<0.001$). Alteration type 4 even led to a significant *decrease* of the speed driven ($p<0.01$). It could be argued that the markings that were available on these roads in the baseline situation, already provided some kind of guidance therefore not leaving any 'need' for guidance that could be fulfilled by the added (or replacement with an) edge line. The fact that, in the baseline situation, the mean speed at these roads was higher than the mean speed on the roads without any markings, seems to support this explanation.

#### 3.1.5.2. Effects on variation in speed

From the viewpoint of the principle of homogeneity the effects of altered road markings on the variation in speed between road users might be even more important than the effects on mean speed. A total of 231 effect sizes were available for estimating the effect of altered markings on the variation in speed between road users (For one of the experiments, one coder reported the standard deviation whereas the other did not. The standard deviation was not reported in the publication but could be calculated using the raw data). Both decreases and increases of the variation in speed were found, with a maximum decrease of 2.9 km/hour (Krammes & Tyer, 1991; experiment 2) and a maximum increase of 3.9 km/hour (Krammes & Tyer, 1991; experiment 5). The mean effect was an increase with 0.06 km/hour, which is negligible (s.d.=1.3).
It might be interesting to note that the two extremes mentioned above were found in experiments that resulted in the same effect on mean speed (an

increase of 4.2 km/hour). These experiments were carried out by the same group of researchers and consisted of replacing post-mounted delineators with raised pavement markers supplementing the painted centre line at curves on two-lane rural highways (Krammes & Tyer, 1991). So even when a similar effect on mean speed is found, the effect on speed differences between road users might be different. In a similar way, some experiments in which no effect was found on the mean speed resulted in an increase of the variation in speed between road users of as large as 3 km/hour. But in general, the effect of altered road markings on the variation in speed between road users is negligible (0.06 km/hour).

### 3.1.5.3. Effects on lateral position

A total of 369 effect sizes were calculated for the effect of road markings on the lateral position of road users (for one of the experiments, one of the coders did not code the entire experiment). Shifts both to the centre and the edge of the road were found, with a maximum shift to the centre of 124 centimetre (Pyne et al., 1995; experiment 15) and a maximum shift to the edge of the road of about 80 centimetre (Lundkvist et al., 1992; experiment 1). *Figure 3.2* shows a histogram of the effect sizes regarding lateral position. The mean effect was - 0.5 centimetre, which corresponds to a shift of the lateral position of 0.5 centimetre towards the centre of the road (i.e. hardly any shift of the lateral position; s.d.=23.8). *Figure 3.2* clearly shows that in a small group of experiments (n=4 including duplicates due to double coding), an extreme shift of the lateral position towards the centre of the road took place. It turned out that their experimental road markings consisted of narrowing the lane widths with one or one-and-a-half metre. When these studies were disregarded, the mean effect was a lateral position that was 0.8 centimetre closer to the edge of the road (s.d.=17.15).
To check whether the effects on lateral position are different for the different types of alterations, the range of effect sizes found as a result of these alterations, and their mean and standard deviation are presented in *Table 3.3*.

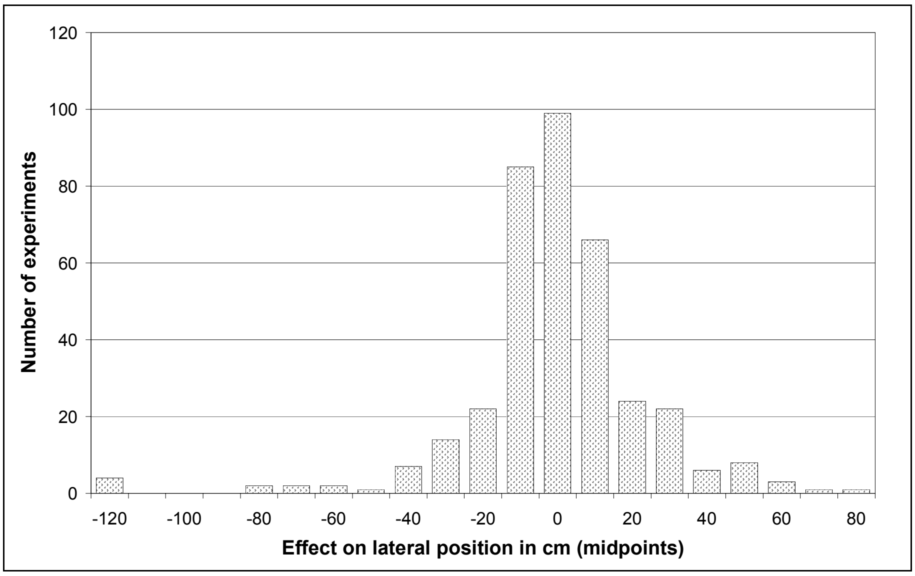


Figure 3.2. *Histogram of the effect on lateral position (in cm from the centre of the road)*

| Type of alteration | | N[1] | Range | | Mean | Standard deviation |
|---|---|---|---|---|---|---|
| | | | min | max | | |
| 1. | no lines => centre line (cl) | 30 | -19 | 48 | 12 | 20 |
| 2. | no lines => edge line (el) | 22 | -15 | 48 | 10 | 16 |
| 3. | cl => cl + edge line | 85 | -27 | 35 | -1 | 11 |
| 4. | cl => no cl + edge line | 20 | -42 | 21 | -12 | 21 |
| 5. | cl+el => cl+'other type of el' | 80 | -117 | 80 | -3 | 30 |
| 7. | cl+el => 'other type of cl'+el | 38 | -30 | 58 | 2 | 18 |
| 8. | cl+el => variation of both cl+el | 4 | -18 | 8 | -5 | 15 |
| 9. | alterations involving RPMs | 52 | -41 | 52 | 4 | 21 |
| 10. | other alteration | 38 | -124 | 29 | -10 | 38 |

[1]Since not all experiments have studied the effect on lateral position, the number of effect sizes can differ from the number of studies reported in Table 3.1.

Table 3.3. *Effects on lateral position (in cm from the centre of the road) of different types of alterations of road markings*.

Although the standard deviations show that there is still a large degree of variation in the effects on lateral position found within the groups of experiments that tested the same types of alterations, there are some significant differences ($p<0.001$) between the mean effects found by the different types of alterations. Whereas the experiments that consisted of adding a centre line or an edge line to a road that did not have any painted markings (*Table 3.3*, types 1 and 2) found a significant shift of the lateral position towards the edge of the road ($p<0.01$), experiments in which the existing centre line was replaced with an edge line (*Table 3.3*, type 4) found a significant shift of the lateral position towards the centre of the road ($p<0.02$). Perhaps the marking of a previously unmarked road gives the driver a better feeling of the preferred (in case of a centre line) or possible (in case of an edge line) lateral position. The effect of the replacement of a centre line with an edge line could be the result of edge lines that are not placed on the edge of the pavement (for instance to make room for non-compulsory cycle lanes), therefore leading to a shift of the lateral position to the centre of the road as compared to the baseline situation in which no edge line was available. This effect will be studied in more detail in *§ 3.5*, since the alteration concerned is the same as the one that was proposed for access roads.
A shift towards the centre of the road was also found in the experiments grouped in 'other alterations' (- 10cm). However, due to the large differences within this diverse group of alterations, this effect was not significantly different from zero. But the mean effect found in this group (-10 cm) did differ significantly from the effects found in the experiments on roads with no markings in the baseline situation (12 cm and 10 cm; $p<0.01$ and $p<0.02$ respectively). The largest contribution to the shift of 10 centimetres towards the centre of the road, comes from the small group of experiments mentioned before, in which the carriageway was narrowed on the last straight section before a bend (Pyne et al., 1995; ). As a result of this narrowing, lane widths in the experimental situation were one or one-and-a-half metre narrower than before. The effect on the mean lateral position (on

the entire road section) varied from 56 up to 124 centimetres towards the centre of the road.

3.1.5.4. Effects on variation in lateral position

As opposed to variations in speed between road users, variations in lateral position between road users are generally not associated with negative effects on road safety. For this reason, the effects of altered road markings on the variation in lateral position will not be examined in detail.
A total of 234 effect sizes were available for estimating the effect of altered markings on the variation in lateral position between road users. Both decreases and increases of the variation in lateral position were found, with a maximum decrease of 31 centimetre (Krammes & Tyer, 1991; experiment 2) and a maximum increase of 36 centimetre (Lundkvist et al., 1992; experiment 2). The mean effect was a decrease of 0.2 centimetre (s.d.=9.0).

### 3.1.6. *Publication bias*

Funnelplots were produced to inspect whether certain types of results (e.g. zero or very small effects) were not or sparsely present in the documents included in the meta-analysis, which would indicate publication bias. The funnelplot idea is based on the operation of the law of large numbers, which states that the larger the sample size, the more probable it is that the sample mean is a good estimate of the population mean (Mullen, 1989). On the horizontal axis of a funnelplot the effect sizes are shown, on the vertical axis the sample sizes on which the effect sizes were based. According to the law of large numbers, there will be less variation in the effect sizes of the larger samples, and more variation in the effect sizes of smaller sample sizes. If there is no publication bias, the plot should resemble this situation, resulting in a distribution that takes the shape of an inverted funnel. *Figure 3.3* shows the funnel plots of the effect on speed and lateral position.

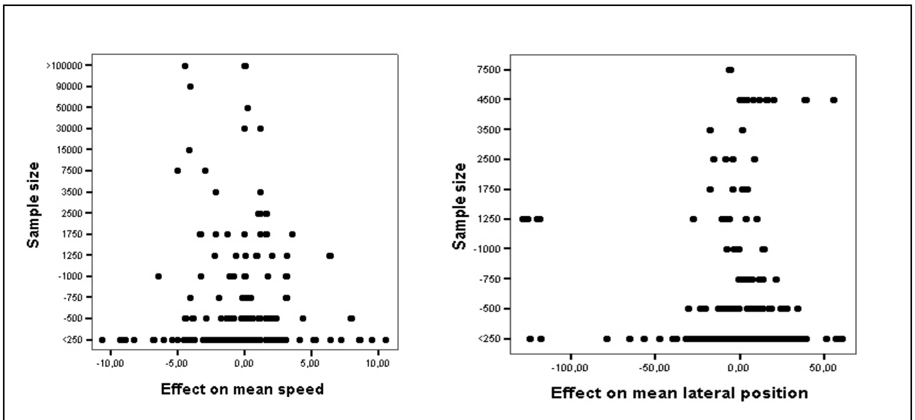


Figure 3.3. *Funnelplots of the effects of altered road markings on speed and lateral position by sample size.*

In both plots the distribution of data points resembles the shape of an inverted funnel quite well, although it could be argued that negative effects on the mean lateral position (i.e. shifts to the centre of the road) are a bit underrepresented in the dataset.

## 3.2. The alterations in accordance to “essential characteristics”

Our main focus for the rest of this report will be on the alterations that are needed to arrive at a situation in which roads have markings that are in accordance with the guidelines proposed in the document on 'essential characteristics' (see § *1.4*). When the proposed road markings for the three types of roads that are distinguished in a sustainably safe traffic system are compared with the current road markings on these road types (see *Figure 1.2*), the changes that have to be made seem to correspond to the following alterations available in the dataset described above (numbers refer to the alteration types mentioned in *Tables 3.1 to 3.3*):
- through road: type 7 (centre line + edge line vs ‘other type of cl’ + el).
- distributor road: type 8 (cl + el vs ’variation of both cl and el’).
- access road: type 4 (centre line vs edge line).

However, the alterations of road markings mentioned in *Table 3.1* are only broad categories of alterations that were grouped according to the changes that were made in the experimental situation. A closer inspection of the alterations revealed that there were still large variations within these categories. For example, a variation of the edge line could be changing the spacing or width of the edge line or replacing a continuous line with a broken one, or the other way round. The alterations which are necessary to obtain the proposed markings for access, distributor and through roads are, however, very specific. Therefore, all the alterations included in the three categories mentioned above were closely studied to select, per type, those alterations that are really comparable to the alterations needed according to *Figure 1.2*.

It turned out that the alterations needed for through roads and access roads corresponded to a subset of type 7 and 4 respectively. But the alterations needed for distributor roads matched none of the alterations included in the category stated above (type 8). The variations included in this category turned out to be related to the widening of both the centre line and the edge line, whereas the alterations needed for distributor roads are doubling and continuation of the centre line and changing the continuous edge line into a broken edge line. This combination of alterations was not studied in any of the experiments coded in this meta-analysis. As an alternative way to find data on the effects to be expected from the alterations needed for distributor roads, we decided to split up the alterations needed into those needed for the centre line and those needed for the edge lines. The former alterations (doubling and continuation of the centre line) turned out to be the same as the ones needed to obtain the proposed markings for through roads (a subset of type 7). The latter alterations (changing the continuous edge line into a broken edge line) turned out to correspond to a subset of the alterations 'type 5'.
Since the current markings on through roads and distributor roads are exactly the same, the effects of the changes needed to obtain the proposed markings for distributor roads can be derived from the combined effect of those subsets of alteration type 7 and alteration type 5 that correspond to type A and B shown in *Figure 3.4*. Alteration A corresponds to the alterations needed to obtain the proposed markings for through roads, and alteration B corresponds to the alteration that would be needed to change the proposed markings for through roads into the proposed markings for distributor roads.

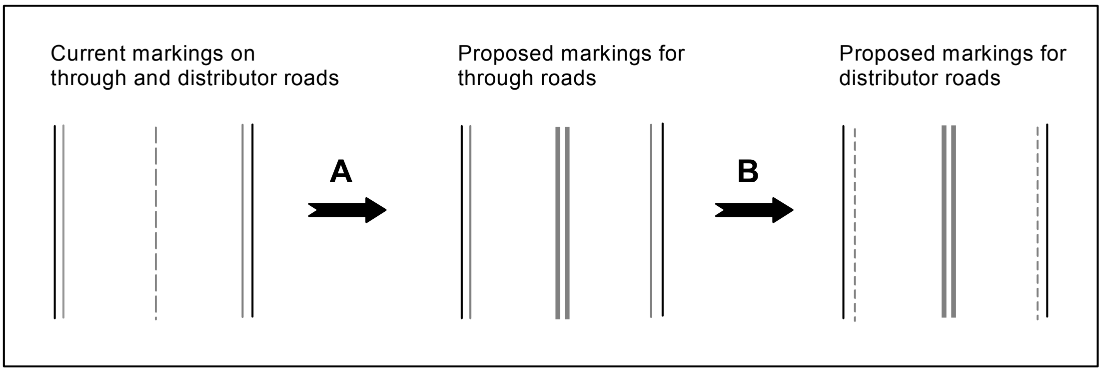


Figure 3.4. *Changes needed to obtain the proposed markings for distributor roads*.

In the next paragraphs, the characteristics will be studied of the three categories of alterations mentioned above (subsets of type 7, type 5 and type 4). Since we use subsets of the types of alterations mentioned in *Table 3.1*, the number of experiments will be smaller (remember that all frequencies relate to the number of codings, which is twice as large as the number of experiments). In fact, the numbers might become too small to draw conclusions on the effects of the proposed alterations of road markings on speed and lateral position. But these experiments are the only ones available that could give us some insight in the effects. If only the analysis of these experiments gives us an idea of the direction of the effect on speed (increase or decrease) or lateral position, that will be more than we currently know about the effects of the markings proposed for the sustainably safe road categories.
Every road category will be discussed in a separate paragraph. Each paragraph starts with a presentation of the basic statistics of the experiments that studied the alterations of the respective category. After that, the effects of the alterations will be described.

## 3.3. Results for the alterations relevant for through roads

The changes that will have to be made to obtain the proposed road markings for through roads are shown at the top of *Figure 1.2* (and at the left side of *Figure 3.4*). The proposed centre line for through roads consists of two continuous lines with between these lines a different colour of paint, a wide central reserve (median), or a guard rail. Since our database only contains alterations that involve longitudinal pavement markings, only the first type of centre line could be found in the database (although it did not include the different colour between the two centre lines). The changes needed to obtain this type of marking, were studied in three experiments (two studied the effect of a double continuous centre line, one studied the effect of a triple continuous centre line). We will refer to these changes as type T1 (T for through road; see *Appendix D*). The characteristics of these experiments are shown in the second column of *Table 3.4*.
Three other experiments studied similar changes: the experimental markings corresponded to those proposed for sustainably safe roads but the centre line in the baseline situation was continuous instead of broken. We will refer to this type of alteration as type T2. Another type of alteration that is similar to type T1 involves the same change of centre line, but has broken edge lines in both the baseline and the experimental situation. We will refer to this type of alteration as type T3.

All types of alterations were studied on 2-lane roads outside urban areas with a speed limit between 70 and 100 km/hour. These speed limits are a bit lower than the speed limit on through roads (at least 100 km/hour). Except for one experiment, all experiments were carried out between 1995 and 1998. Whereas all experiments of type T1 were carried out in the Netherlands, all experiments of type T3 were carried out in the United Kingdom and the experiments of T2 were carried out either in the United States of America or in the Netherlands.

| | Type T1<br>(n=6) | Type T2<br>(n=6) | Type T3<br>(n=4) |
|---|---|---|---|
| Year | 1996-1998 | 1976/77, 1998 | 1995 |
| Country | NL | NL (67%)<br>USA (33%) | UK |
| Road type | 2-lane road outside urban area | 2-lane road outside urban area | 2-lane road outside urban area |
| Speed limit | 80 km/hour | 72 km/hour (33%)<br>80 km/hour (67%) | 97 km/hour |
| Research design | Before vs after (33%)<br>Experimental vs control road: on the same road (67%) | Before vs after (67%)<br>Experimental vs control road: on the same road (33%) | Before vs after |
| Observation method | Static observations | Static observations | Driving simulator |
| No of observations (mean)<br>- baseline situation<br>- experimental situation | <br>3607<br>3771 | <br>3143<br>3156 | <br>56<br>56 |
| Effect on speed (sd) | 4 km/h (0) n=2 | 4 km/h (0) n=2 | -2 km/h (2) n=4 |
| Effect on lateral position (sd) | 4 cm (13) n=4 | -6 cm (16) n=6 | 28 cm (34) n=4 |

Table 3.4. *Characteristics of experiments that studied changes relevant for through roads and of those that studied similar changes.*

Unfortunately, not all of the experiments studied the effects on both speed and lateral position. As a result, the already low sample sizes for the three types of alterations are even smaller when it concerns the effects on speed and lateral position (note that the number of experiments is half the sample size mentioned in *Table 3.4*). Due to these small sample sizes, no conclusions can be drawn on the effect of the alterations needed to obtain the proposed markings for through roads.

## 3.4. **Results for the alterations relevant for distributor roads**

The changes that will have to be made to obtain the proposed road markings for distributor roads, starting with the proposed markings for through roads, were studied in five experiments. These changes correspond to the alteration shown at the right side of *Figure 3.4*. We will refer to these changes as Type D (D for distributor road; see *Appendix D*). The characteristics of these experiments are shown in *Table 3.5*.

| | Type D<br>(n=10) |
|---|---|
| Year | 1995 |
| Country | UK |
| Road type | 2-lane road<br>outside urban area |
| Speed limit | 97 km/hour |
| Research design | Before vs after |
| Observation method | Driving simulator |
| No of observations (mean)<br>- baseline situation<br>- experimental situation | <br>52<br>52 |
| Effect on speed (sd) | 0 km/hour (2) n=10 |
| Effect on lateral position (sd) | 4 cm (9) n=10 |

Table 3.5. *Characteristics of experiments that studied changes relevant for distributor roads (starting with the markings proposed for through roads).*

All experiments were carried out in a driving simulator in the United Kingdom in which 2-lane roads outside urban areas were simulated. All roads had a speed limit of 97 km/hour, which is higher than the speed limit that is and will be in effect on distributor roads outside urban areas (80 km/hour). This could affect the usability of the results for estimating the effects of the alterations needed to obtain the proposed markings for distributor roads.

Changing road markings from the ones proposed for through roads to the ones proposed for distributor roads (alteration B in *Figure 3.4*) does not lead to any significant changes in speed (0 km/hour) or lateral position (4 cm). One could therefore state that there will be no difference in the effect of changing the current road markings on distributor roads into those proposed for distributor roads (with broken edge lines) or into those for through roads (with continuous edge lines). However, since the effects of the alterations needed for through roads could not be derived in the previous paragraph due to small sample sizes, the actual effects on speed and lateral position of the alterations needed for both through roads and distributor roads are still unknown.

## 3.5. Results for the alterations relevant for access roads

The changes that will have to be made to obtain the proposed road markings for access roads, were studied in six experiments. These changes correspond to the alteration shown at the bottom of *Figure 1.2*. We will refer to these changes as type A1 (A for access roads). The characteristics of these experiments are shown in the second column of *Table 3.6*. Two other experiments studied similar changes: the experimental markings corresponded to those proposed for sustainably safe access roads but the markings in the baseline situation consisted of a broken centre line and continuous edge lines (see *Appendix D*). Although the baseline situation in these two experiments differed from the one shown at the bottom of *Figure 1.2,* this combination of road markings can actually be found on roads that are categorized as access roads, so they are in fact relevant for our research. We will refer to these changes as type A2. Another type of alteration that is similar to type A1, has the same markings as those in the baseline situation of type A1, but has continuous instead of broken edge lines in the experimental situation. We will refer to this type of alteration as type A3.

| | Type A1 (n=12) | Type A2 (n=4) | Type A3 (n=10) |
|---|---|---|---|
| Year | 1995-2000 | 1993-1995 | 1995-1996 |
| Country | NL | NL | NL |
| Road type | 2-lane road outside urban area | 2-lane road outside urban area | 2-lane road outside urban area |
| Cycle-lane available in experimental situation | yes (17%)<br>no (83%) | Yes (100%) | no (100%) |
| Speed limit | 60 km/hour (17%)<br>80 km/hour (83%) | 80 km/hour | 80 km/hour |
| Research design | Before vs after (17%)<br>Experimental vs control road: on different roads (83%) | Before vs after | Experimental vs control road: on different roads |
| Observation method | Instr. Vehicle (50%)<br>Static obs. (50%) | Static observations | Instr. vehicle (60%)<br>Static obs. (40%) |
| No of observations (mean)<br>- baseline situation<br>- experimental situation | <br>411<br>407 | <br>26745<br>42412 | <br>108<br>196 |
| Effect on speed (sd) | -2 km/h (1) n=8 | 1 km/h (1) n=4 | -1 km/h (2) n=6 |
| Effect on lateral position (sd) | -8 cm (24) n=10 | - | -15 cm (18) n=10 |

Table 3.6. *Characteristics of experiments that studied changes relevant for access roads and of those that studied similar changes*.

All experiments were carried out on 2-lane roads outside urban areas in the Netherlands between 1995 and 2000. All roads but one had a speed limit of 80 km/hour in the baseline situation. It should be noted that this speed limit is not what it should be according to the guidelines for the design of sustainably safe roads. The speed limit on access roads outside urban areas should be 60 km/hour. Only one experiment used the right speed limit in both the baseline and experimental situation. In one other experiment (of type A2) the speed limit was changed from 80 km/hour in the baseline situation to 60 km/hour in the experimental situation.

In three experiments the experimental situation provided a red non-compulsory cycle lane in the area outside of the broken edge line. Two of those experiments belong to type A2 and the third belongs to type A1. The cycle lanes had a width of 75, 100 and 120 centimetre respectively.

The changes of type A1 led on average to a reduction of the mean speed by 2.4 kilometres per hour. The other types of alterations led to smaller effects on the mean speed driven: either an increase or decrease by 0.7 kilometres per hour. The mean effect found in group A1 is the only one that significantly differs from zero ($p<0.001$), although some reserve is in order because of the small sample size and a distribution of the data that deviates from the normal distribution. It is, however, safe to say that on average changing the markings on access roads into markings that are in accordance with those proposed, leads to a substantial decrease of the mean speed driven.

As a result of the changes of type A1, the mean lateral position on average shifted 8 centimeters towards the centre of the road. Due to large variations within the group of experiments, this shift did not significantly deviate from zero. The changes of type A3 did lead to a significant shift of the lateral position ($p<0.05$); on average the mean lateral position shifted 15 centimetres towards the centre of the road.
In *§ 3.1.5.3* it was suggested that the shift of the mean lateral position towards the centre of the road could have been the result of edge lines that were not applied on the edge of the pavement but closer to the centre of the road. The red non-compulsory cycle lanes mentioned above are a good example of this situation. However, these cycle lanes did not influence the mean shift in lateral position, since the studies that investigated the effects of cycle lanes only studied the effects on speed and did not report on the lateral position of the vehicles. Therefore, the position of the edge line in these experiments does not seem to have influenced the mean effect on lateral position (closer to the centre of the road).

# 4. Discussion

This meta-analysis showed that adding an edge line or a centre line to a road that was previously unmarked leads to an increase in the speed driven and a shift of the lateral position towards the edge of the road. The first effect was expected based on previous narrative reviews (e.g. Van der Hoeven, 1987; Steyvers, 1994; Claassen & Pouwels, 1998; Rumar & Marsh, 1998): the visual guidance provided by adding longitudinal road markings, leads to higher speeds. However, an increase in the speed driven was not found when an edge line was added to a road that was already marked with a centre line or in case a centre line was replaced with an edge line. Quite the contrary, the latter alteration even led to a decrease of the speed driven. It could be argued that the markings that were available in the baseline situation already provided some kind of guidance, therefore not leaving any 'need' for guidance that could be fulfilled by the added (or replacement with an) edge line. The fact that, in the baseline situation, the mean speed on these roads was higher than the mean speed on the roads without any markings seems to support this explanation.

Based on the abovementioned findings, marking an unmarked road seems to lead to undesirable effects on road safety. Not only because of higher speeds, but also because of a shift of the lateral position towards the edge of the road. Both have been related to negative effects on road safety, the first one (speed) based on more evidence (Finch et al., 1994, Aarts, 2004) than the second one (lateral position; Mäkinen et al., 1999). The actual effects on road safety are, however, not known, since accident data were not included in the studies on which this meta-analysis was based.

In the Netherlands, road markings will have to be changed as part of the implementation of a sustainably safe traffic system (Van Schagen & Janssen, 2000). According to the principles of this traffic system, road users should be able to recognize the function of the road they are driving on, and thereupon automatically "know" the way they should behave. To achieve this, it has been proposed to use distinct road markings for the different categories of sustainably safe roads (access roads, distributor roads and through roads). In most cases, the proposed road markings differ from the current ones. Therefore, road markings will have to be altered. This meta-analysis showed that, so far, very few studies have evaluated the effects of these alterations on the mean speed and lateral position of road users. Only the effects of the alterations needed to obtain the proposed markings for access roads have been evaluated in enough experiments to be able to draw some conclusions. The mere implementation of these alterations (i.e. without additional information on the purpose of the alteration) appears to have a small positive effect on road safety: the mean speed decreased and the lateral position tended to shift towards the centre of the road.
Given that the implementation of the proposed road markings for the three categories of sustainably safe roads will affect many Dutch roads, it will be very important to monitor the effects of the altered road markings on the speed and lateral position of road users. This will give insight into the actual relationship between the proposed road markings, the recognizability of road types and the speeds driven on them. Depending on the outcome, decisions

can be made on the necessity of extra measures to improve the recognizability of road types and/or to achieve the desired effects on road user behaviour. It might for instance be necessary to inform road users about the purpose of the altered road markings for them to associate speed limits with road types and their specific markings.

Finally, some limitations of a meta-analysis of the results of practical research studies are worth mentioning. First, although the aim was to include all relevant studies in our meta-analysis, it is still possible that we missed certain studies. Secondly, although the statistical procedures that we used assume independence of the experimental comparisons included, this was actually not always the case. For example, some research groups studied the effects of several alterations of road markings. All of these effects were included in our meta-analysis. It is not clear whether this led to dependency of study results. Third, only in a minority of the experiments included in our meta-analysis a control site was used to correct for uncontrollable factors. Effect sizes that are corrected for the effects found on control sites are often smaller than uncorrected effect sizes.
Fourth, our decision to include the datasets of both coders into our database, to avoid losing the extra information provided by one of the coders, could have influenced the significance of some of the effects we have found (because of the inflated sample size). We tested whether this was the case. It turned out that the effects with the highest levels of significance (the effects on speed and the differences in effects found for different types of alterations on both speed and lateral position) were also significant ($p < 0.05$) when using the dataset of (either) one of the coders. This means that the inclusion of the datasets of both coders into our database did not put us on the wrong track. The main conclusions of our study, as reported at the beginning of this discussion, would have been the same if we had used the dataset of (either) one of our coders.
Finally, we would like to mention that the number of studies available for the meta-analysis of the effects of the proposed markings for sustainably safe road categories was too small to examine the influence of moderator variables on the variation in effect size. Study characteristics such as time of day (night or day) or road environment (open field, trees, buildings) might explain (a part of) the effect size variation. Another study characteristic that might have influenced the variation of effect sizes is the country of study. On certain US roads one can and is allowed to drive on the paved shoulders of the road, whereas on most European roads (including Dutch roads) this is not allowed and often not even possible because most roads (except motorways) do not have paved shoulders. As a result, drivers on European roads might be less tempted to drive on the right side of the road than drivers on US roads. These differences might have affected the effects of altered road markings on the lateral position of road users.

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# Appendix A References for studies included in the meta-analysis

1. Total set of included studies

2. References for through roads

3. References for distributor roads

4. References for access roads

## 1. Total set of publications*:*


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# Appendix B Calculation of the effect size for lateral position

Some of the coded lateral positions were measured from the edge of the road and others were measured from the edge of the centre line. In case the comparison of diferent road markings includes changes in lane width (for instance in case-control studies in which the experimental road is smaller than the control road) these different reference points (centre or edge of the road) will lead to different effect sizes. We therefore decided to convert the coded lateral positions while calculating the This led to the following formulas for the calculation of the effect size for lateral position:

*In case of coded lateral positions measured from the edge of the centre line*
efflp = (eslp+.5*esascm) - (bllp+.5*blascm)

*In case of coded lateral positions measured from the edge of the road*
efflp = (esrijscm+.5*esascm-eslp) - (blrijscm+.5*blascm-bllp)

*Where:*
eslp = mean lateral position in the experimental situation (after)
bllp = mean lateral position in the baseline situation (before)
esascm = width of the centre line in the ES (if unknown: 10 cm)
blascm = width of the centre lin in the BS (if unknown: 10 cm)
esrijscm = lane width in the ES (if unkown: .5*pavement width - .5*esascm)
blrijscm = lane width in the BS (if unkown: .5*pavement width - .5*blascm)

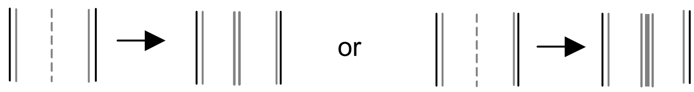
# Appendix C Correspondence between coders

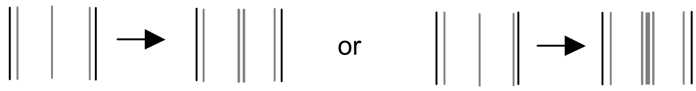
| Continuous variables[1] | Pearson Corr. Coeff. | Categorical variables[1] | Cramer's V |
|---|---|---|---|
| Speed limit (before/control) | 0.98 | Year of experiment | 0.97 |
| Speed limit (after/experimental) | 0.98 | Country | 1.00 |
| Pavement width (before/control) | 1.00 | Publication form | 1.00 |
| Pavement width (after/experimental) | 1.00 | Road type | 0.84 |
| Lane width (before/control) | 0.98 | Type of road section | 0.97 |
| Lane width (after/experimental) | 0.99 | Road environment | 0.65 |
| Width of the edge strip (before/control) | 1.00 | Research design | 0.92 |
| Width of the edge strip (after/exp.) | 1.00 | Observation method | 1.00 |
| Number of observations (before/control) | 1.00 | Weather conditions | 0.69 |
| Length of the experimental road section | 0.70 | Light conditions | 0.94 |
| Line width (centre line) | 1.00 | Influence of drivers that drive in opposite direction | 0.62 |
| Length of broken centre line | 0.84 | Influence of drivers that drive in the same direction | 0.84 |
| Gap of broken centre line | 0.96 | Available markings | 0.99 |
| Line width (edge line) | 1.00 | Number of centre lines | 0.98 |
| Length of broken edge line | 1.00 | Continuous or broken centre lines | 1.00 |
| Gap of broken edge line | 1.00 | Continuous or broken edge line | 0.99 |
| Mean speed (before/control) | 1.00 | Alteration of road markings | 1.00 |
| Sd speed (before/control) | 0.97 | | |
| Mean lateral position (before/control) | 0.99 | | |
| Sd lateral position (before/control) | 1.00 | | |
| Mean speed (after/experimental) | 1.00 | | |
| Sd speed (after/experimental) | 0.97 | | |
| Mean lateral position (after/exp.) | 0.99 | | |
| Sd lateral position (after/experimental) | 1.00 | | |
| Effect on speed | 1.00 | | |
| Effect on sd speed | 0.98 | | |
| Standardised effect on speed | 0.92 | | |
| Effect on lateral position | 0.94 | | |
| Effect on sd lateral position | 1.00 | | |
| Standardized effect on lateral position | 0.64 | | |

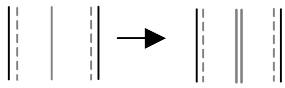
[1] Except for variables related to the effect sizes, all association measures are based on the coded values for the baseline situation. Association measures for the variables that concern the experimental situation hardly differed from those for the baseline situation.

# Appendix D Types of alterations relevant for sustainably safe road categories

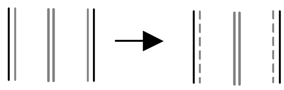
**Alterations relevant for through roads: Type T1 – T3**

T1= 

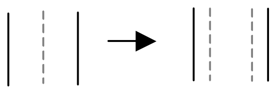

T2= 

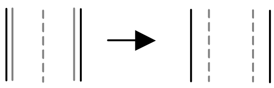

T3= 

**Alteration relevant for distributor roads: Type D**

D= 

**Alterations relevant for access roads: Type A1 – A3**

A1= 

A2= 

A3=