SPEED-REDUCING MEASURES FOR 80 KM/H ROADS

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ABSTRACT

Control of driving speeds offers an important possibility to improve traffic safety on rural 80 km/h roads. In The Netherlands, about 50% of all people killed in traffic occur at these roads, partly due to high speeds. An experimental project in Drenthe was aimed at the development and testing of measures that effectively reduce speed without significantly reducing driving comfort up to Speeds of 80 km/h. First, some variants of proposed infrastructural measures were tested in a driving Simulator before actual application. Secondly, a resulting set of four basic design elements was implemented on four 80 km/h road sections in Drenthe and evaluated in terms of the actual driving behaviour, including both speed and lateral placement.

In the Simulator study, the experimental conditions consisted of two lane-widths (2.75 and 2.25 m) and three experimental lay-outs of edge Strips, viz. one with a continuous profiled road marking, one with small lateral rumble Strips every 5 meter, and one every 10 meter. On entering this edge Strip (the 2.75 m lane had a Strip of0.20 m and the 2.25 m lane one of 0.70 m) auditive feed-back by means of sound and steering-wheel Vibration was generated. A conventional 80 km/h road (lane-width 2.75 m) with Standard road delineation served as control condition. Two instructions (relaxed vs. driving under time-pressure) were varied between subjects.

The results show that the narrow lane width (2.25 m+0.70 m edge Strip) gives the largest speed reductions and is fairly resistent to effects of adaptation. Moreover, the narrow lane width especially reduces the speeds of drivers under time-pressure, implying that also in practice speed variance may be reduced. The different lay-outs of the edge Strips reveal relatively small differences in driving behaviour. In summary, it is concluded that the basic design elements as developed in this project offer a good prospective for reducing driving speeds in practice.

The evaluation of the resulting set of measures on four test locations in Drenthe, based upon the analysis of inductive loop data, indicated that a sustainable speed reduction of about 2 km/h was achieved. Video-observations revealed that, in spite of the reduced lane width of smooth asphalt, the 0.30 m central chipping strip marking (instead of 0.10 m conventional central marking) results in a lateral placement of minimally 0.10m away from the centre of the road. Apparently, drivers refer mainly to the near-by side of the central marking. So, with respect to lateral placement no negative safety effects have to be expected. Over a two-year period a 20% reduction in the number of accidents was reached, whereas at the control locations an 8% increase occurred.

1. INTRODUCTION

In The Netherlands, rural 80 km/h roads have the highest accident rates of all road types. In general, high speed is assumed to contribute substantially to the occurrence of these accidents. Therefore, reduction of driving speeds may offer a high potential for improving traffic safety on 80 km/h roads. The experimental project "Speed Reducing Measures on 80 km/h Roads in Drenthe" - Drenthe being one of the 12 Provinces in The Netherlands - was started in 1990 and aimed at the development and testing of measures that effectively reduce driving speed without significantly reducing driving comfort up to speeds of 80 km/h. At speeds above 80 km/h an increasing discomfort was aimed for. Especially, measures to the road and/or road-environment were explored that result in a 'natural' lower speed choice by the motorist and also reduce speed variance among cars. Measures of this type are well in line with recent developments of Sustainable Road Safety and Self-Explaining Roads (Koornstra et al., 1992, Theeuwes & Godthelp, 1992).

By including knowledge of human information processing and of driver behaviour, in brainstorm sessions with representatives from the local, regional and national government, research institutes, consultancies, and police, a package of basic design elements for 80 km/h roads was identified and compiled (Heidemij, 1992). Some variants of the proposed measures were tested in a driving Simulator study with respect to driving behaviour (van der Horst & Hoekstra, 1992, 1994). The resulting design elements were further optimized by Computer simulations by testing some roadsurface unevenness patterns on vehicle comfort and tyre-road contact (Hoogvelt & Jansen, 1992). The final package of speed-reducing measures was implemented on four experimental 80 km/h roads in Drenthe and evaluated in terms of speed behaviour and traffic safety for a period of over two years.

2. SPEED-REDUCING MEASURES

In a literature review on determining factors of speed choice, Tenkink (1988) distinguishes several behavioural models, of which the utility model is the most general one. Speed will be reduced when the risk or discomfort caused by an high speed increases. In weighing the pros and cons of an high speed, both the probability and the size of the consequences are important. For example, Tenkink (1989) found a reduction in speed when a narrow road width was combined with threatening obstacles along the road. But also perceptual speed adaptation, uncertainty, and task demand may play a significant role in drivers' speed choice. Negative consequences of a high speed (discomfort, threat) may be effective if they are consistent and real, and if the involved risk is detectable, recognizable, and verifiable. Although an increasing threat, uncertainty, or workload may reduce speed, traffic safety may not necessarily improve as well (Tenkink & van der Horst, 1991). Since drivers may react differently to given measures, with a possible increase in speed variance, measures must provoke uniform behaviour to the greatest extent as possible. Furthermore, on a narrow road the visual guidance may be better than on a wide road, which may result in an increase in speed. These considerations resulted in a basic design for 80 km/h roads consisting of four main elements, viz.: lane width, edge marking, centre marking, and verge reminders (Heidemij, 1992).

Laue Width

An important basic assumption in the design is that the net available lane width for car drivers is reduced as much as possible. It takes some manoeuvring effort to make use of the so-called "smooth" asphalt part of the lane. Deviations from the right course must result in discomfort at speeds above 80 km/h, but without inducing unsafe situations. Another constraint is to ensure that heavy vehicles (trucks, buses) are not impeded at speeds up to 80 km/h. In order to meet both requirements a net lane width of "smooth" asphalt between 2.25 and 2.75 m was proposed, together with a profiled edge marking that makes up a total road width of6.20 m.

EdgeMarking

A second assumption of the basic design is that no excessive visual guidance should be present. Therefore, it was proposed to implement no visual edge marking by delineation, but to use a "tangible" one instead in combination with the additional width needed for heavy vehicles. This edge marking must be designed in such a way that drivers of heavy vehicles do not notice much discomfort, but drivers of passenger cars experience discomfort that increases with speed.

Centre Marking

Reducing the visual guidance by the edge markings requires drivers to get their information on the course of the road primarily from the centre markings. The centre marking must be clearly visible (also during darkness and bad weather) and represent a unique code for 80 km/h roads. Therefore, a 0.30 m centre line (instead of a 0.10 m one) with 3 m long white lines at a 9m spacing was proposed, preferably with a "tangible" component.

Verge Reminders

In The Netherlands, reflectors posts at a height of0.60 m every 40 m usually support the visual guidance. To reduce the visual guidance these road-side reflectors are removed and replaced every 500 m by so-called verge reminders uniquely designed for 80 km/h roads. In the Simulator study, these four basic elements in the road design of80 km/h roads were included.

3. SIMULATOR STUDY

3.1 Method

The aim of the Simulator study is to gain insight in the functioning of the proposed measures in terms of driving behaviour before measures are actually implemented on the road. In general, results from Simulator studies with respect to speed choice indicate that the relative validity is acceptable (Riemersma et al„ 1990; Tenkink, 1990; Tenkink & van der Horst, 1991). However, absolute speed levels have to be interpreted with caution because one tends to drive faster in a driving Simulator than in the real world.

The experiment was conducted in the fixed-base driving Simulator of the TNO Human Factors Research Institute. At the time of the experiment, this Simulator had a MEGATEK 944 CGI-system that generated the visual scene (1024 x 1024 pixels) at a refresh-rate of 30

Hz. These images were displayed on a large screen in front of the vehicle mock-up (a Volvo 240) by a high resolution projector BARCOGRAPHICS 800 (van der Horst, Janssen & Korteling, 1991). The horizontal visual angle of the projected image was about 50 angular degrees. Nowadays., the TNO driving Simulator has been equipped with a three channel Evans & Sutherland ESIG 2000 CGI System, enabling a horizontal visual angle of 120 degrees. Recently, a simple moving base System (MOOG 6DOF2000E) has been added (Hoekstra, van der Horst & Kaptein, 1997).

The independent variables of the simulator-experiment included: instruction (relaxed, timepressure), lane width (2.25 m and 2.75 m smooth asphalt), and edge-stripe configuration (continuously profiled marking strip, small cross rumble Strips every 5 m, and small cross rumble Strips every 10 m). The centre line of the experimental roads consisted ofa0.30 m continuous profiled marking with every 12 m a series of three white blocks of 0-80 x 0.30 m at a mutual distance of0.30 m. Entering the centre or edge marking with one of the wheels resulted in an auditive feed-back to the driver via a loud sound in the vehicle and a Vibration in the steering wheel. At the beginning of each experimental road the symbol "80" was painted on the road surface A Standard rural road with conventional delineation, a lane width of2.75 m, and post mounted reflectors every 40 m, served as a control condition. Each subject drove each condition three times.

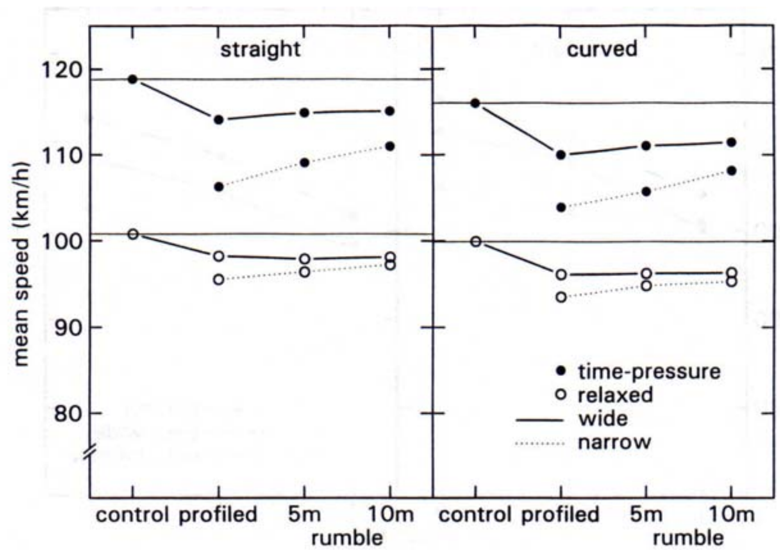
In total, 32 male subjects participated in the experiment. The age varied between 21 and 53 years (average 35.5). Subjects were paid for their participation.

Dependent variables included speed, Standard deviation (s.d.) of speed, lateral position, s.d. of lateral position, and the number and duration of left and right lane exceedances. Separate analyses of variance (ANOVAs) have been conducted on the driving behaviour variables on straight road sections and in curves (100 m before and 100 m after the curve included). For a more extensive description of the experiment the reader is referred to Van der Horst and Hoekstra (1992,1994).

3.2 Results Speed

The proposed measures aimed at reducing speed. Figure l gives the speed, averaged over subject, and repetition, as a function of instruction, lane width ("smooth" asphalt) and the three experimental configurations of the edge strip. The results of the control condition with the conventional 80 km/h road are added as a reference. The absolute speed levels appear to be often rather high in a driving Simulator. Also in this study, even for the instruction relaxed driving the absolute speed values are well over 80 km/h. Instruction has an important effect on speed. Subjects under time pressure drive about 15 km/h faster on the straight road sections (113 vs. 98 km/h, $F(l,228)=15.0$, $p<0.001$), and 14 km/h faster in curves (110 vs. 96 km/h, $F(l,28)=10.9$, $p<0.005$). The main effect of lane width just does not reach significance ($F(l,28)=3.6$, $p<0.07$). It appears that under time pressure the speed on the narrow lanes is significantly lower than on the wide lanes (t-test, $t=3.4$, $p<0.002$). A narrow lane especially reduces the speed of the drivers that are in a hurry. The three edge strip configurations differ only for the narrow lane width (interaction width x configuration $F(2,56)=7.5$, $p<0.002$). In combination with the narrow lane width, the configuration with the continuous profiled marking reduces speed speed somewhat more than the two other configurations. So, the configuration with the most direct feed-back to the driver gives the best results.

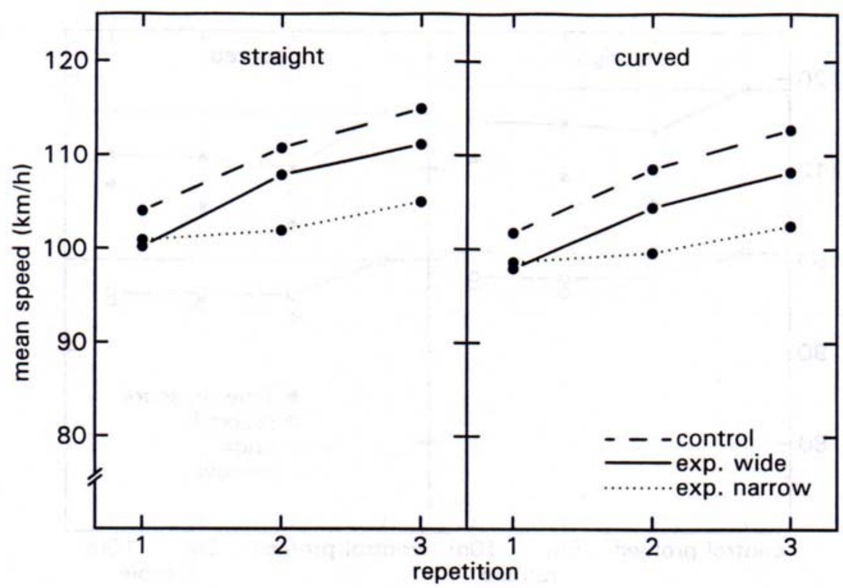
***Figure I**: Speed on straight (left) and curved (right) road section as a function of instruction. lane width (wide = 2.75 m. narrow = 2.25 m), and edge Strip configuration.*



Repetition appears to have a main effect on speed (F2,56)=38.3, $p<0.0001$). Speed increases with repetition, but the speed on the narrow lanes increases relatively the least (interaction lane width x repetition $F(2,56)=7.5$, $p<0.002$), see Fig. 2.

By analyzing the difference between the speed on an experimental road and the control road section within the same block, the effect of repetition can be compensated for. Then, an ANOVA reveals a main effect of lane width (F(l,28)=40.2, $P<0.0001$). The narrow lane gives the highest speed reduction. Combined with the narrow lane, the edge Strip configuration with the continuous profiled marking reduces speed more than the 5 or 10m rumble (interaction lane width x configuration $F(2,56)=7.5$, $p<0.002$).

Figure 2: *Mean speed of on straight (left) and curbed (right) road sections as a function of repetition, control section and lane width.*



Lateral placement

For each subject the average lateral position relative to the centre of the road has been calculated for both straight and curved road sections. ANOVAs reveal that neither repetition, instruction, or edge Strip configuration has an effect on lateral position. As can be expected lane width has far the greatest effect on lateral position ($F(l,28)=509$, $p<0.0001$). In the wide lane one drives 1.22 m from the middle of the road, whereas the narrow lane results in a lateral position of 0.99 m, compared with 1.08 m in the control condition (straight road sections). The lane keeping behaviour for both lane widths differs significantly from that in the control condition (mean lateral position 1.18m) (wide lane vs. control, $t=4.04$, $p<0.001$; narrow lane vs. control, $t=2.58$, $P<0.02$).

The s.d. of lateral position is independent of repetition, instruction, and edge Strip configuration. Compared with the control condition, the experimental lanes reduce the s.d. of lateral position ($F(3,84)=52.4$, $p<0.0001$) with the narrow lane having the strongest effect (s.d. lateral position on straight road sections on control, wide lane and narrow lane 0.18, 0.15, and 0.12 m, respectively). In the narrow lane condition drivers steer more accurately.

4. IMPLEMENTATION ON THE ROAD

The results of the Simulator study show that the narrow lane width (2.25 m+0.70 m edge strip) gives the largest speed reductions and is fairly resistent to effects of adaptation. Moreover, the narrow lane width especially reduces the speeds of drivers under timepressure, implying that also in practice speed variance may be reduced. The different layouts of the edge Strips reveal relatively small differences in driving behaviour. The basic design elements as developed in this project offer a good prospect for reducing driving speeds in practice. To optimise the final physical characteristics of the edge strip mathematical Computer simulations have been conducted (Hoogvelt & Jansen, 1992). These simulations resulted in an edge strip of4 m long blocks of chippings with a spacing of4 m. Together with the reduced lane width of smooth asphalt of 2.25 m and a 0.30 m central chipping strip marking, the removal of the white edge lines and post-mounted reflectors on straight road sections, this basic design package of speed reducing measures was tested on four experimental road sections in Drenthe, see Fig. 3. This package of measures was expected to be effective at reasonable costs, maintenance friendly, and in case of failure relatively easy to remove again.

Figure 3: *Basic design package of speed-reducing measure as tested in Drenthe.*

4.1 Speed measurements

At the four experimental road sections and at five comparable control sections speed measurements with inductive loop detectors have been conducted for a period of in total over two years (Steyvers, 1995). After a before measurement, at each location speeds have been measured quarterly during a period of four weeks, 24 hours a day. The effect of the speed-reducing measures after one year appeared to be about 2.1 km/h, as an average over all experimental locations in comparison with the control locations. After the second year the effect was reduced till about 1.7 km/h, on average. In the same period, some physical wear of the chipped edge Strips was noted with, as a result, a reduction in discomfort (Laméris, 1994).

4.2 Lateral placement

From the results of the Simulator study some concerns existed with respect to the lateral placement of drivers due to the physical measures. Would drivers choose a lateral position in the traffic lane closer to the middle of the road with, as a consequence, a higher risk on head-on collisions? To quantify the effects of the measures on the lateral placement of vehicles, the driving behaviour at one experimental location was compared with that at a conventional 80 km/h road (lane width 2.75 m, and Standard road delineation of a 0.10 m centre and edge lines) by means of a quantitative analysis of video recordings (van der Horst & Bakker, 1994). The analysis of cumulative distributions of the lateral placement of free driving vehicles (both passenger cars and trucks) at both sites reveals that the package of speed-reducing measures does not result in a lateral placement more to the middle of the road. In contrary, the 0.30m central chipping strip marking (instead of the 0.10 m conventional central marking) even results in a lateral placement of minimally 0.10 m more away from the centre of the road, see Fig. 4. Drivers mainly seem to refer to the most nearby side of the central marking. At the moment on-coming traffic is passing, the lateral placement is not influenced at all by the measures. Apparently when passing, drivers orientate completely on the other vehicle, the mutual distance between two passing vehicles does not differ at all between the experimental and control location, see Fig. 5.

Figure 4: *Cumulative distributions of lateral placement of the left (LW) and the right (RW) wheel of free-driving passenger cars at the experimental and control location, relative to the middle of the road (0 cm)*

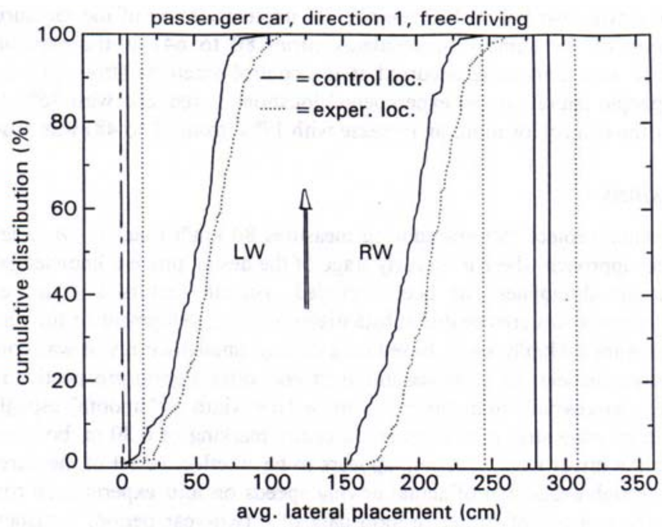
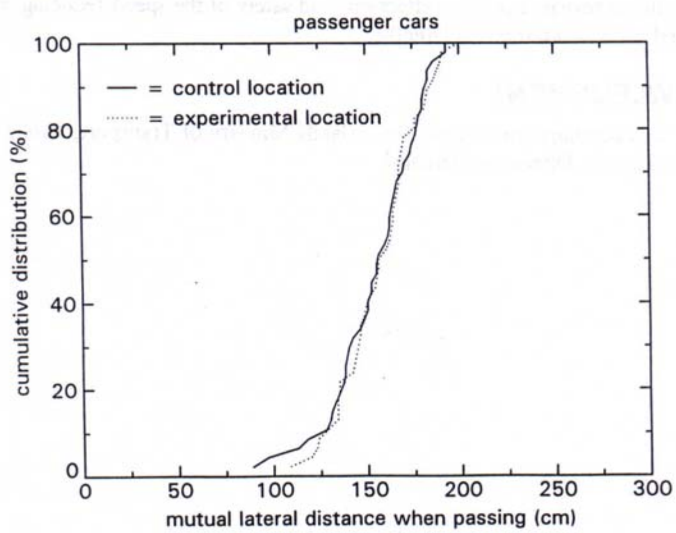


Figure 5: *Cumulative distributions of the mutual distance between passenger cars at the moment of passing at the experimental and control location.*



4.3 Accidents

An analysis of all police-reported accidents at the experimental locations and at the control locations for a two-year period before-and-after implementation of the measures reveals a 20% reduction of the number of accidents (from 80 to 64) at the experimental road sections, while an 8% increase occurred at the control locations (from 119 to 129). The number of people injured at the experimental locations is reduced with 36% (from 28 to 18), while at the control locations an increase with 17% (from 41 to 48) was observed.

5. CONCLUSIONS

The experimental project "Speed-reducing measures 80 km/h roads in Drenthe" is a good example of an approach where in an early stage of the design process knowledge and know-how of various disciplines has been included. Human factors knowledge based on behavioural research has contributed substantially to the development of the resulting basic design package for 80 km/h roads. Based on a driving simulatorstudy, it was concluded that the basic design elements as proposed in this project offer a good prospective for reducing driving speeds successfully in practice. A narrow lane width of "smooth" asphalt of2.25 m together with an edge Strip of0.70 m and a centre marking of0.30 m, both with acoustic feed-back to the driver when crossing, appears to be an effective set of measures to reduce speed. A thorough evaluation of actual driving speeds on four experimental road sections, based upon the analysis of inductive loop data of a two-year period, a sustainable speed reduction of about 2 km/h could be achieved. In spite of a reduced lane of smooth asphalt and a discomfort edge Strip, a 0.30 m central chipping strip marking results in a 0.10 m lateral placement shift away from the centre of the road. Apparently, drivers mainly focus on the near-by side of the central marking. A two year before-and-after comparison of accident statistics reveals a positive effect on road safety of the speed-reducing measures. as implemented on 80 km/h roads in Drenthe.

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