# A Driving Simulator Evaluation of Enhanced Road Markings

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## Biography

Dr Tim Horberry is a human factors psychologist employed at the Monash University Accident Research Centre. He is interested in road, rail, aviation and maritime safety. Tim has many publications in the road safety field, and recently co-edited a book about the human factors of transport signs.

## Abstract

This paper details research undertaken by the Monash University Accident Research Centre (MUARC) comparing the relative effectiveness under simulated wet night driving conditions of an enhanced painted road-marking technology and Standard highway markings. Both objective and subjective data were collected. The study found consistently superior results for the Enhanced markings in comparison to the Standard markings in various measures of driving behaviour. Similarly, workload was rated as lower for the Enhanced markings. Taken together, the findings point to a potential safety benefit from using Enhanced roadway markings.

## 1 INTRODUCTION

Improving night-time visibility has been shown to be a major factor in reducing accidents (Sanders and McCormick, 1993). Furthermore, improving visibility for drivers on wet nights has been long identified as an area requiring more attention (Boyce, 1981). The importance of providing painted edge lines and centre lines on highways has been demonstrated by a study that found that the presence of such lines reduced accidents by 20% (Miller, 1992).

On wet nights, the visibility of edge lines and centre lines can often be reduced because a film of water lying on the painted line diminishes the amount of light reflected directly back to the driver. Edge lines and centre lines with high retro reflectivity when wet might therefore improve safety.

For almost half a century glass beads embedded in painted markings have been used in road marking delineation. The glass beads are designed to reflect light from the headlights, and so provide reflected light to help guide the driver (Kalchbrenner, 1989). However, the small size (less than one mm diameter) of the glass beads used in Standard road markings in Australia often causes a major loss of retro-reflectivity in the rain. Larger glass beads (greater than one mm diameter) have been shown to be more retro-reflective and to provide more effective wet night visibility (Kalchbrenner, 1989).

Therefore, the general aim of this research was to evaluate the effect under simulated wet night driving conditions of an enhanced visibility highway delineation line technology developed by Potters Industries Ltd (termed '*Visibead'* in the remainder of this paper) compared to Standard highway markings on a series of driver behavioural, workload and other subjective measures.

Specifically, the study aimed to establish whether road markings with greater retro reflectivity make it easier for drivers to negotiate curves, maintain a constant position on the road, and drive more safely. The effects on performance of driving with the Visibead road markings were compared with those for the Standard road markings during simulated driving on a wet night when there was oncoming traffic and glaring headlights.

## 2 METHOD

The research comprised a controlled study in the MUARC advanced driving simulator. This simulator is the most advanced in the Southern Hemisphere. Details of the simulator, including recent upgrades to it, can be found at http://www.general.monash.edu.au/muarc/simsite/simhome.html.

Before the experimental trials began, extensive development and evaluation took place to ensure that the simulated markings were realistic and accurate compared to 'real world' markings.

One major part of this development and evaluation involved an independent panel of road marking experts from around Australia who, on two separate occasions, evaluated the realism of the markings created in the simulator. A second major part involved visiting real roads displaying the markings: the researchers viewed the Standard and Visibead markings in both daylight and night-time conditions. At night, the markings were viewed on dry and wet roads (with the aid of a water truck to spread water on the road). The researchers recorded their observations by means of static digital images, moving digital images (taken from inside a vehicle) and measurements of visibility distances. The distances for which each type of marking was visible when illuminated with high beam car headlights was re-created in the simulator.

*Subjects*
In total, 25 subjects completed the study. There were 13 drivers aged less than 30 years (mean age 23.6 years) and 12 drivers aged over 55 years (mean age 61.1 years).

*Design*
The study was a mixed factorial design with each participant completing all conditions in the experiment. The within-subjects factors were type of road markings (Standard and Visibead) and additional task (present and absent). Two groups of

participants were tested: young and older drivers. Each subject participated in the following four experimental conditions:

- Driving with the ***Standard*** markings with ***no additional task***
- Driving with the ***Visibead*** markings with ***no additional task***
- Driving with the ***Standard*** markings whilst undertaking ***the additional mental arithmetic task***
- Driving with the ***Visibead*** markings whilst undertaking ***the additional mental arithmetic task***

The effects of the Standard and Visibead markings could therefore be examined both when the driver was just driving, and when he or she had to undertake an additional task whilst driving. The additional task was used to assess whether the Visibead markings were more effective when the driver was under greater mental load.

The additional task used was mental arithmetic. Participants wore headphones and heard the stimulus being spoken. They responded verbally via a microphone. They were presented with a two-digit number, such as 47. They were required to mentally separate this number into 4 and 7, and then give the absolute difference between the two numbers. In this example, the answer was 3. The task was forced-paced with a new number being presented every two seconds.

The driving environments were approximately 6 km in length. The gradient was level, but several curves were contained within the drive. Speed limit signs were placed in all the scenes, with the posted speed limit set at 100 km/hr. The road was single carriageway in either direction.  Each lane was 3.2 metres wide; therefore the total road width was 6.4 metres.

Because the simulator used a series of projectors to display the visual images to participants, it was not possible to create the effect of optical glare directly. A specially devised 'glare technique' was therefore used to simulate the glare of an oncoming vehicle's headlights. As this experiment was designed to assess the safety benefits of two marking types when driving on a wet night, simulating the effects of glare caused by bright headlights of oncoming vehicles was considered to be vital. To achieve this, a purpose built light source, comprising two LED luminances mounted on the bonnet of the simulator, was used to simulate the effects of glare caused by oncoming vehicle headlights.

These two LEDs were developed so that when a trigger was pressed, they shone for a period of five seconds (a realistic period for which a driver might see oncoming headlights). The intensity of the light level was also especially created to simulate the varying brightness levels of oncoming vehicles. The brightness increased for approximately the first three seconds, remained at maximum intensity for the next 1.5 seconds and then decayed rapidly (but not instantly) for the next 0.5 seconds. The decay period simulated the glare experienced when an oncoming vehicle becomes level with the driver's vehicle. The operation of the LEDs was linked to the simulator so that they were triggered at the same predefined points in all four experimental conditions.

In order to simulate the appearance of reflections created by water on the windscreen and in the environment, plastic cling wrap was placed on the windscreen of the simulator vehicle. This had the effect of making the view of the driving scene slightly hazy, as would be visually experienced when driving in the rain at night.

*Procedure*
Each subject was tested individually. Upon arrival, they were informed about the study and completed a questionnaire deriving basic information about them (such as their age). After completing the questionnaire, they were introduced to the driving simulator and shown the functions of the vehicle. They then took part in a training trial for approximately five minutes to familiarise them with the simulator vehicle and experimental tasks.

Following this, they undertook the 4 experimental drives (Visibead markings with and without a mental arithmetic task, and Standard markings with and without a mental arithmetic task). Presentation order of these was counterbalanced to prevent order effects across subjects and conditions. Subjects were instructed to drive normally and to obey the speed limits. The general instructions for the different drives were as follows:

> *"Drive as you normally would, and obey the road rules. Drive as closely as possible to the indicated speed limit. Continue driving until you are instructed to stop."*

After each drive, subjects completed a NASA-TLX workload questionnaire and associated material to assess perceived workload during the previous drive. Each drive consisted of 6 minutes of simulated night-time driving, so in total the whole experiment lasted approximately one hour per subject.

Both objective and subjective data were collected. Objective measures included variations in roadway position (lateral lane deviation and crossings of edge and centre lines), mean speed and variations in vehicle speed. The subjective measures were obtained to gauge participants' experiences of the different driving conditions, including workload, perceived driving performance, frustration, confidence and how easy/hard they found the different drives.

## 3 RESULTS

The research amassed a large number of results for objective measures of driving performance as well as driver workload and other ratings. The main results of the study are briefly outlined below.

*Objective results*
In terms of the overall objective results, the study found that subjects drove closer to the target speed of 100 km/h, and were better able to maintain this target speed, when viewing scenes with Visibead markings. Likewise, standard deviations of speed and lateral lane position, and crossings of edge and centre lines were significantly lower with the Visibead markings - thus subjects were able to maintain a more constant level of driving performance with these markings.

To illustrate the findings of one measure in more detail, ‘Standard Deviation of Lateral Lane Position’ examines how much a driver is able to maintain a constant lateral road position. In other words it is a gauge of how much a driver ‘weaved’ across the road. With this measure, less deviation is considered ‘better’ (i.e. holding a more constant lateral lane position). The mean results for the four conditions are shown in Figure 1 below. The values are averaged across all subjects using a predefined start point approximately 1 km into each drive. Data were recorded for approximately 5 km in each drive.

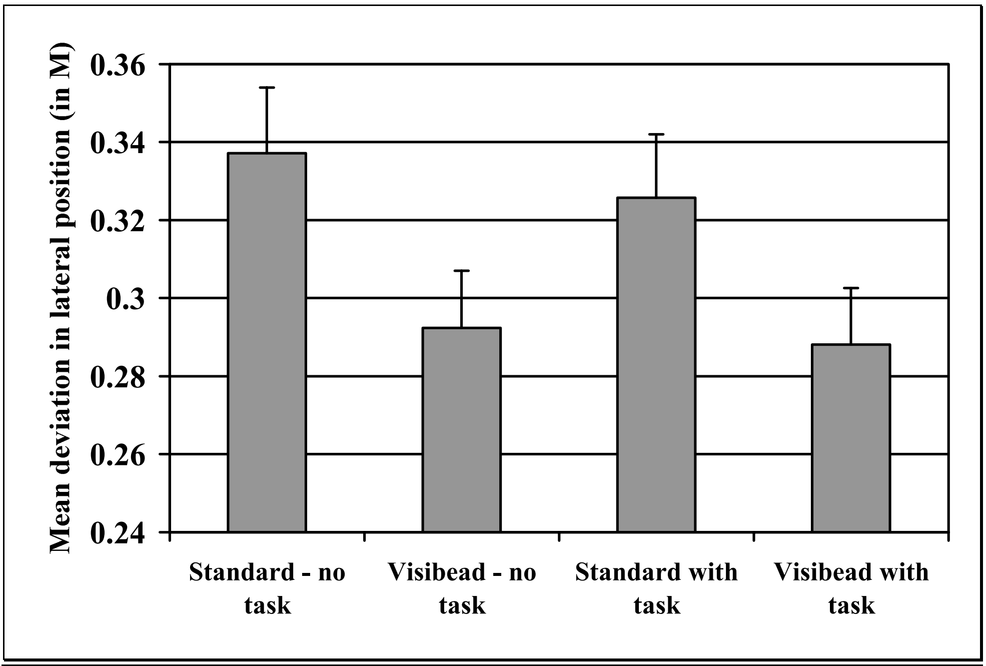


Figure 1: Mean Standard Deviations of Lateral Lane Position for the Four Conditions.

A *General Linear Model* test showed a significant effect for the type of marking (df=1,18, F= 5.756, P=0.03), indicating that drivers held a more constant roadway position in the two drives with Visibead markings compared to the two drives with the Standard markings.

No effects were found for the additional task (the mental arithmetic task), and no differences were found between young and old drivers. This implies that the results obtained with the markings were consistent for different driver ages and whether or not secondary tasks (such as conducting mental arithmetic) were being performed whilst driving.

A similar pattern was found when the analyses focused on drivers’ behaviour for the period during which they were subjected to glare from oncoming traffic. During the approach of oncoming vehicles, subjects maintained the target speed better and varied less in speed and lateral lane position when viewing scenes with Visibead markings. Subjects also did not need to reduce their speed as much when they were exposed to the glare of oncoming traffic with Visibead compared to Standard markings. This suggests that they were better able to safely see the roadway, so did not need to compensate as much by slowing down. No effects were found for the mental arithmetic task, so the effects of superior driving performance with the Visibead markings were also found when participants needed to undertake an additional mental arithmetic task whilst driving.

*Subjective Results*

The subjective measures produced results that were fairly much in line with the objective data. Workload (as measured by the well-validated NASA-TLX technique) was rated as lower for the Visibead markings. This was true for overall workload as well as for the workload sub-scales of mental demand, physical demand, temporal demand, perceived performance, effort and frustration. Unsurprisingly, subjects also rated workload as higher during drives when they had to perform the secondary mental arithmetic task (although this was not reflected in their actual performance).

The overall NASA-TLX workload score is an average of the workload subscales. The results are shown in Figure 2 below. Workload was scored on a scale that ranged from 0-20. Low values indicate lower workload.

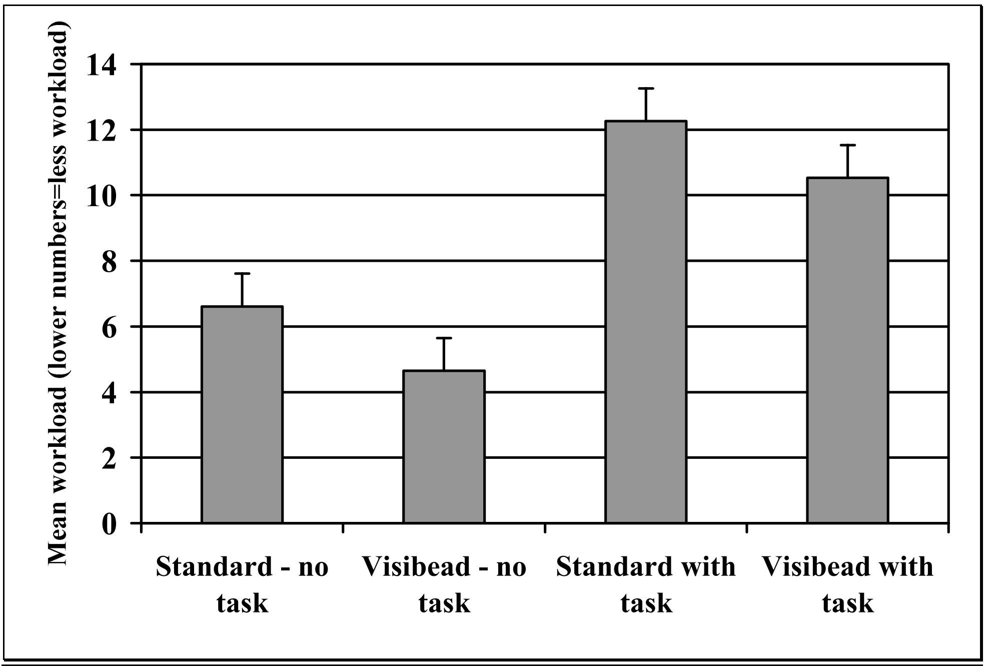


Figure 2: Mean Workload Ratings for the Four Conditions

It can be seen that perceived workload was significantly lower when the roads were marked with Visibead markings. A *General Linear Model* test showed a significant effect for the type of marking (df=1, 23 F=23.53, $p<0.001$). This means that participants rated workload lower in the two drives which showed the Visibead markings than for the two drives that showed Standard markings. Additionally, workload was lower when there was no distraction from an additional task. The *General Linear Model* showed a significant effect of type of task used (i.e. no task or an additional task) (df=1, 23, F=71.90, $p<0.001$), indicating that workload was rated as lower when they were not required to perform the mental arithmetic task.

Likewise, subjects reported the drives as being easier with the Visibead markings (and being easier when no additional mental arithmetic task was required). Subjects were more confident in being able to drive safely when the roads displayed the Visibead markings compared to when they drove with the Standard markings, and more confident when they did not need to perform the additional mental arithmetic task. No differences between younger and older drivers were found on any of these measures, showing that the superior results obtained with the Visibead markings were consistent for different driver ages.

Overall, the study found superior results for the Visibead markings in comparison to the Standard markings. Participants were better able to maintain lane position and speed with the Visibead markings - often they were around 30% better. This occurred both when people were driving along the whole of the test drive and when data were selected from the period during which they were subjected to the potential hazard of glare from oncoming traffic. Superior driving performance with the Visibead markings was also found when participants needed to undertake an additional mental arithmetic task whilst driving. A similar pattern was found for the subjective measures. Workload was rated as lower for the Visibead markings; likewise, subjects reported the drives as being easier with the Visibead markings. Finally, subjects were more confident in being able to drive safely when roads displayed Visibead markings compared to when they displayed Standard markings.

## 4 DISCUSSION AND CONCLUSIONS

One important issue is the fact that this study was a simulator experiment. Whether the results found here will generalise to the 'real world' needs to be confirmed by future studies. However, the authors argue that the study was a well-controlled experiment - being a formal procedure in which the types of markings were systematically manipulated. Further, it was undertaken in a well-validated advanced driving simulator- many previous studies have shown that the results of this simulator closely correlate to real world driving performance (e.g., Godley, Triggs and Fildes, 1997). Also, before the actual study was undertaken the researchers spent a great deal of time making the scenes as realistic as possible (for example by getting independent marking experts to view the scenes created). As such, it is argued that the results are a meaningful comparison between the Visibead and Standard markings.

The experiment obtained a large number of different types of objective driving performance and workload / subjective data. The study found consistently superior results for the Visibead markings in comparison to the Standard markings. With the objective data, the Visibead markings produced results that previous research have found to be associated with a reduction in accident rates. These were:

- better lateral lane control – indicated by lower deviations in lateral lane position, fewer crossings of edge and centre lines and less time outside lanes;
- better speed control; and
- better maintenance of a target level of performance (i.e. driving closer to a predefined speed).

Similarly, in terms of subjective ratings, the Visibead markings show the following in comparison to Standard markings:

- are less mentally, physically and temporally demanding;
- produce a higher level of perceived performance;
- less effort required when driving;
- are less frustrating; and
- yield higher confidence in ability to drive safely.

Taken together, the findings suggest that likely safety benefits might emerge from greater use of enhanced markings on roads around Australia.

## 5 REFERENCES


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