TECHNICAL PAPER

SPEED MANAGEMENT ON RURAL ROADS: THE EFFECT OF PAVEMENT MARKINGS

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ABSTRACT

This study investigates the effect on speed of the presence of painted edgelines and centrelines on straight, single carriageway rural roads. The paper is based on the author's Masters in Engineering Transportation thesis.

Research suggests that people drive without conscious awareness for a high proportion of travel time, particularly on longer trips. Many well-practised driving tasks become automated with experience. Mental pictures (schemata) combine to evoke automatic responses over time (scripts) based on cues from the environment. Unintentional speeding arises either due to inexperience (in the case of novice drivers), or due to the driver relying on cues from the road environment without explicit awareness.

Engineering can therefore affect driving behaviour at an unconscious level by providing a road environment that engenders appropriate speed by its design.

The research hypothesis proposes that pavement markings (continuous edgelines and broken centrelines) signal a certain standard of road by their presence or absence. The hypothesis was tested on straight, single carriageway, rural roads using matched pairs, and a before/after study. Results showed a significant increase in speed on roads with a centreline, compared to no markings, and with a centreline and edgeline, compared to centreline-only. While there are clearly many influences on driver speed choice (both to do with and independant of the road environment), this research suggests that the presence of pavement markings has a significant effect on speed.

INTRODUCTION

Current New Zealand guidelines encourage the installation of painted centrelines and edgelines on sealed rural roads within recommended sealed width ranges. The Manual of Traffic Signs and Markings (MOTSAM) states that centrelines are desirable on all sealed rural roads, and edgelines are recommended on all rural roads with a sealed width of at least 6.6m (NZTA, 2009a). A typical rural road centreline and edgeline are shown in Figure 1.

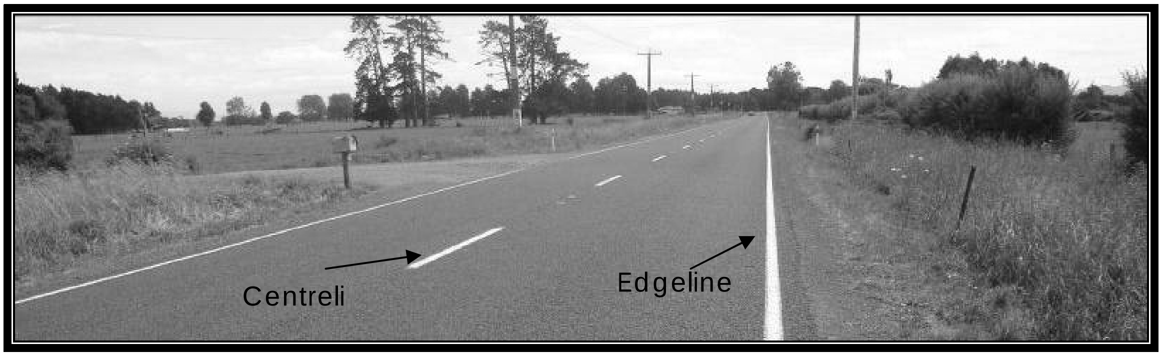

Figure 1 Rural Road Edgeline and Centreline

These guidelines are in place as it is understood that the presence of pavement markings is beneficial (Miller, 1992; Carlson et al., 2009). Pavement markings can be beneficial in that they provide information to the driver about road alignment, help the driver maintain appropriate lane position and reduce mental effort (Steyvers & de Ward, 2000).

This paper presents an investigation into the effect of edgelines and centrelines on speed. While the guidance provided to drivers by these markings may or may not reduce the frequency of certain types of accidents, no conclusive research has as yet isolated the separate effect of centrelines and edgelines on speed. This effect is important because if the presence of these markings leads to higher speeds, the safety benefits assumed by their installation (via a reduction in the frequency of certain crash types) may be negated to some extent.

Research Questions

Research questions are

1) How does the presence of a centreline on a rural road affect the speed distribution?
2) How does the presence of an edgeline on a rural road affect the speed distribution?
3) If the presence of pavement markings affects speed, how does this in turn affect traffic safety?

Background

It is widely accepted that higher speeds lead to an increase in both accident frequency and severity (e.g. Weller et al., 2008). In rural environments, it has been estimated that for every 1km/h increase in speed, there is a corresponding 4% increase in the number of fatal accidents (Kloeden et al., 2001). Speeds are greatest on rural roads, where most fatal accidents happen. In 2008 in New Zealand there were 39,907 reported road traffic accidents in total. Of these, 31% of all accidents and 73% of fatal accidents occurred on rural roads (NZTA, 2009b).

The current research looks into speed management on rural roads, because speed management potentially improves safety across all accident types and for all types of rural road user. Of all potential engineering interventions in a rural road environment, pavement markings are among the cheapest to install.

Several studies have isolated the safety benefit gained by installation of edgelines and centrelines. These pavement markings have been shown to reduce the frequency of run-off-road crashes, as well as reducing the frequency of all night-time crashes. Studies vary in their estimates of the crash reductions gained through installation of markings. While one study found that installation of edgelines reduces crashed by 8% (Miller, 1992), another found no significant accident reduction (Ogden, 1992), while a meta-analysis cited a range of reductions from 4 to 66% (FHWA, 2007). International guidelines estimate that centrelines reduce the frequency of all crashes by 30 to 36% (FHWA, 2007; Elvik and Vaa, 2004), though there is little research offered in support of these figures. The New Zealand guide for installation of markings on rural roads, RTS 5, states:

Centrelines can address lost control and/or head-on accidents by defining the centre of the roadway. No references to the expected accident reduction or BCR have been found.
(Transit New Zealand, 2002)

The installation of pavement markings in New Zealand is controlled in legislation by the Land Transport Rule: Traffic Control Devices 2004, while guidance for road controlling authorities is provided by the Manual of Traffic Signs and Markings (MOTSAM), Part II: Markings. MOTSAM sets out the types of markings to use based on traffic volume and sealed road carriageway. Despite these guidelines, the installation of centrelines and edgelines is inconsistent, particularly on non-State Highway (District Council) roads in New Zealand.

Driver Behaviour Theories

The ultimate aim of speed management through engineering, education and enforcement is to have a road network where speeds are appropriate for the conditions such that accidents are avoided (insofar as inappropriate speeds contribute to accidents). Inappropriate speeds arise from two separate conditions; intentional and unintentional speeding. Intentional speeding involves conscious decision making and is not likely to be significantly affected by pavement markings, therefore this paper discusses unintentional speeding only.

Unintentional speeding arises either due to inexperience (in the case of novice drivers), or due to the driver relying on cues from the road environment without explicit awareness. In cognitive psychological terms, information from the road is used to form mental schemata and scripts.

Schemata relate to spatial information. To save mental effort, drivers subjectively categorise types of roads, and an automatic behavioural response is evoked. For example, features such as concrete median barriers, multiple traffic lanes in each direction and grade-separated interchanges are clear cues that the road is a motorway and therefore of a high standard. Narrow, unmarked country lanes with little traffic and few buildings indicate a lower standard of road where the alignment and adjacent environment are likely to be less forgiving.

Scripts relate to the processing of information over time. They are based on sequences learned through experience. When driving, the brain uses road cues from the environment to draw on stored schemata, which in turn trigger scripts to make unconscious predictions about what lies ahead. Much of the driving task is governed by these automated, unconscious processes, due to the nature of driving as a well-practiced task. Over time, processes such as gear changes, maintenance of speed and lane position, and turning a corner, become automated. The use of schemata and scripts based on cues from the road environment to automate the driving task is referred to as subjective road categorisation.

Speed Choice Theories

It is not surprising that the complexity of the driving task, combined with the prevalence of driving as an everyday activity, has led to the development of several theories of the psychology of driver behaviour. The theory of risk homeostasis for example, first published by Wilde (1982), proposes that accident rate is related to the target risk level sought by a driver or by society as a whole. Therefore if improvements are made to the driving system that change a driver's perception of risk, the theory suggests that drivers will adjust their behaviour to maintain the risk at their original (and unchanging) target levels. Risk homeostasis implies that safety interventions are largely inconsequential and will not achieve much improvement in safety.

Risk homeostasis has been debated such that it is now widely accepted (e.g. OECD, 1990) that while drivers may adapt at some level to perceived changes in the driving task brought about by a certain safety intervention, this behavioural adaptation does not necessarily negate the safety benefit of the intervention entirely. One New Zealand study showed that while speeds increased after road realignment, the increase did not fully negate the safety benefit (Wong and Nicholson, 1992).

Theories of driver behaviour can be helpful in explaining processes potentially at work in the mind of a driver. The finding common to all theories of driver behaviour is that driver behaviour is complex and not simply explained. Accidents are, after all, rare events. Even at New Zealand's most 'high risk' accident sites (where 'high risk' is defined as the highest number of reported injury accidents per vehicle-kilometres travelled, compared to other sites), millions of drivers successfully negotiate the site for every injury-causing collision. Models of driver behaviour are yet to predict where and when such accidents might occur, as the following quote explains:

"The focus on the role of human error has led many psychologists to devote large amounts of energy to creating complex and not very useful models of road user behaviour. Most of these models are only descriptive and are thus neither predictive nor verifiable. They tend to take the form of complex flow diagrams, which often state little more than that human behaviour is not straightforward and that a lot of factors influence it''. Oliver Carsten, in Rothengatter (2002)

Despite this stated non-usefulness of driver behaviour models, engineers in the 21st century are seeking to understand more of driver behaviour to further improve safety on roads. Whether the practice is supported by models or not, many guidelines in transportation now support the 'Safe System' approach (e.g. Environment Waikato, 2009). A common objective of such systems is to work towards self-explaining roads. This objective is discussed further below.

The New Paradigm: Self-Explaining Roads

Designs of road systems in line with road user expectation, with safety considered as a system property, have been studied from the late eighties (e.g. Rimersma, 1988). Roads that elicit safe behaviour by design were first referred to as self-explaining roads in the 1990s (e.g. Theeuwes and Godthelp, 1995). Since that time, considerable research has taken place looking at the components of self-explaining systems generally, and road environments in particular.

A self-explaining road will answer several questions about what drivers might expect to encounter, for example:

- What is the likelihood of encountering slow moving traffic, for example bicycles?
- Are crossings and exits clearly marked and appropriate for the speed environment?
- Is the speed environment consistent; am I going to need to brake to negotiate isolated, out-of-character curves?

In rural environments, motorways are the best example of self-explaining roads. There are no crossings, and exits and entries are grade separated with long merge and diverge tapers to maintain consistently high speeds for all traffic. Bicycles and other slow moving vehicles are barred. The horizontal and vertical alignments are designed to allow consistent speeds, with no out-of-character curves, and therefore no advisory speeds below the posted speed limit. Signs and markings are retro-reflective, so visual cues are visible at night time. The main aspect of motorways that makes them self-explaining is the consistency of application of these principles. It is simply not accepted to have an at-grade crossing on a motorway, or a 50km/h horizontal curve in an otherwise 100km/h posted speed limit environment.

Pavement markings can be beneficial in that they provide information to the driver about road alignment, help the driver maintain appropriate lane position and reduce mental effort (Steyvers and de Ward, 2000). Markings are also useful for the engineer as they are relatively very cheap to install. However, it may be that the guidance provided by pavement markings affects driver speed choice, such that increased delineation leads to increased speeds. This effect has received limited attention in the international literature, and has not been systematically investigated on New Zealand rural roads.

Given that the installation of centrelines and edge lines on New Zealand rural roads is not always consistent with guidelines, there are likely to be examples where the roads are similar in every way, but with pavement markings differing. This situation presents the opportunity for research to isolate the effect of pavement markings on speed.

If pavement markings are shown to affect speed, it is irrelevant to the safety question which theory of driver behaviour explains this effect. It may be that the absence of markings increases a driver's perception of risk, encouraging them to slow down. It may be that a certain type of marking indicates to a driver a certain standard of road through subjective road categorization. It is also possible that different drivers perform the driving task with different conscious and unconscious objectives. Drivers' motives may change over time, within a single journey and throughout the driver's life. This research does not purport to prove one theory of driver behaviour over another. It looks instead at the physics and reality of collisions and road engineering, and asks what the latter might do to affect the frequency and severity of the former, bypassing much of the complex interaction between the two. The usefulness of this research will be in terms of guidelines for the implementation of rural road centrelines and edgelines to optimise safety.

METHODS

Matched Pair Study

To test the effect of pavement markings on speed, the experiment required site comparisons where the only difference between sites is the pavement marking condition (ie no markings, centreline only, or centreline plus edgelines). In a matched pair study, pairs are chosen to be as similar as possible, with only the test condition differing between sites in each pair. In this case, pairs were matched for sealed carriageway width (no greater than 0.5m difference between sites), and selected to have a similar subjective ‘look and feel’. The width assumed for each site was the mean of five measurements including width at the proposed survey site, width 250m from the site in each direction, and width 500m from the site in each direction.

All sites had edge marker posts at varying spacings, and all sites with a centreline also contained reflectorised raised pavement markers (RRPMs). As they were all on straight roads, there were no curve advisory warnings or chevrons at any sites.

Unsealed shoulder widths were not measured as these varied (from zero sealed shoulder to approximately 2.0m) both upstream and downstream of each individual site. Though all roads were flat, the environment beyond the sealed carriageway varied between sites to allow for drainage requirements. Therefore while all sites were well matched subjectively, there were inevitably differences (other than the pavement marking differences) that might have had some effect on driver speed choice..

Sixteen sites (eight pairs) were selected. Four pairs were found to compare 'no marking' roads to 'centreline-only' roads, and four separate pairs were found to compare 'centreline-only' roads to 'centreline-plus-edgeline' roads. All study sites were

- on straight, flat sections of road, not within 500m of any vertical or horizontal curve
- in Waikato District
- within a 40km radius of Hamilton
- single carriageway
- not within 500m of any major intersection
- within a 100km/h posted speed limit area
- surrounded by a mix of agriculture and rural residential land

For this study, analysis is based on free speed, therefore it was not considered necessary to match pairs on the basis of traffic volume.

Sites were selected using a combination of street maps, internet mapping software and site visits. Sites within pairs were also chosen to be close geographically to capture similar vehicle and trip types.

Figure 2 shows site locations. Figure 3 shows an example of a matched pair.

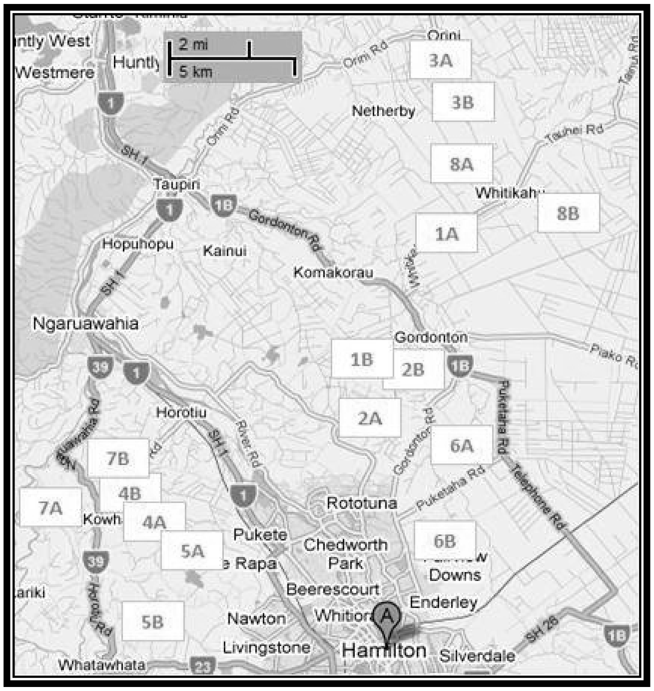

Figure 2 **Matched Pair Site Locations**

Figure 3 Sites 1A (Whitikahu Road, left) and 1B (Boyd Road)

Each site was surveyed with Metrocount automatic tube counters from Friday 20th February to Friday 27th February 2009 to gather traffic volume, vehicle type and speed data. Sites were checked during the survey period. Data from two sites (7A and 8B) were discarded as the tube counters were incorrectly positioned (too close to major intersections). Sites 7A and 8B were coincidentally matched for width, therefore these sites formed the seventh pair for analysis.

Before/After Study

While matched pairs have the advantage of surveys taking place concurrently, sites within pairs will inevitably have differences, other than pavement marking differences, that may affect speed. A before/after study was included to determine the effect on speed of adding an edgeline to a road with centreline only. The results of this study were not available at the time of submission of this paper.

ANALYSIS OF RESULTS

Data Screening

After screening for platooned vehicles and outliers, the dataset included 58,366 speed values over 14 sites, ranging from 909 to 13,214 values per site. Random samples of this data were collected for analysis to provide even amounts of data across each site ($n = 800$). An even number of values representing light, dark, wet and dry conditions were taken from each site. Six random dataset samples were collected and each piece of analysis was carried out six times with different datasets. This was to ensure that the random samples themselves were not unrepresentative of the sample populations.

Differences between Pairs

The speed difference between each site within a pair was analysed using one-way analysis of variance (ANOVA) using the SPSS statistical analysis software. As the data from sites 7A and 8B could not be used, site 7B was matched with site 8A for pair analysis.

Post-hoc tests following one-way ANOVA were used to test for significant difference between observed sample means, using random samples from each site dataset. Results are summarised in Table 1.

Table 1 ANOVA Results for Matched Pairs

Pair	Pavement marking comparison (CL = centreline, EL = edgeline, NM = no pavement markings)	Mean speed difference between sites (averaged across six random samples, km/h)	Significance: Alpha value (range if applicable)	95% Confidence Interval of difference (average lower and upper bounds)
1	CL / CL+EL	16.3	<0.001	13.7 → 19.0
2	CL / CL+EL	-3.2	<0.001 – 0.252	-6.3 → -0.1
3	CL / CL+EL	9.1	<0.001	6.1 → 12.1
4	CL / CL+EL	0.2	0.960 – 1.000	-2.4 → 2.8
5	NM / CL	6.4	<0.001	2.9 → 9.8
6	NM / CL	16.8	<0.001	7.1 → 26.5
7	NM / CL	13.4	<0.001	6.1 → 12.3

The analysis summarised in Table 1 shows that for five of the seven pairs, there is a significant difference in the mean speed between sites. For all of these five pairs, the speed is greater at the site of greater delineation. For example, for Pair 1, there is an average and significant 16 km/h higher speed at the site with edgeline and centreline (Whitikahu Rd), than at the site with edgeline only (Boyd Rd). For Pairs 2 and 4, some speed data samples showed significant difference in speed between sites, and some did not, therefore no significant difference can be claimed. The difference in speed between sites in each pair is shown graphically in Figure 4.

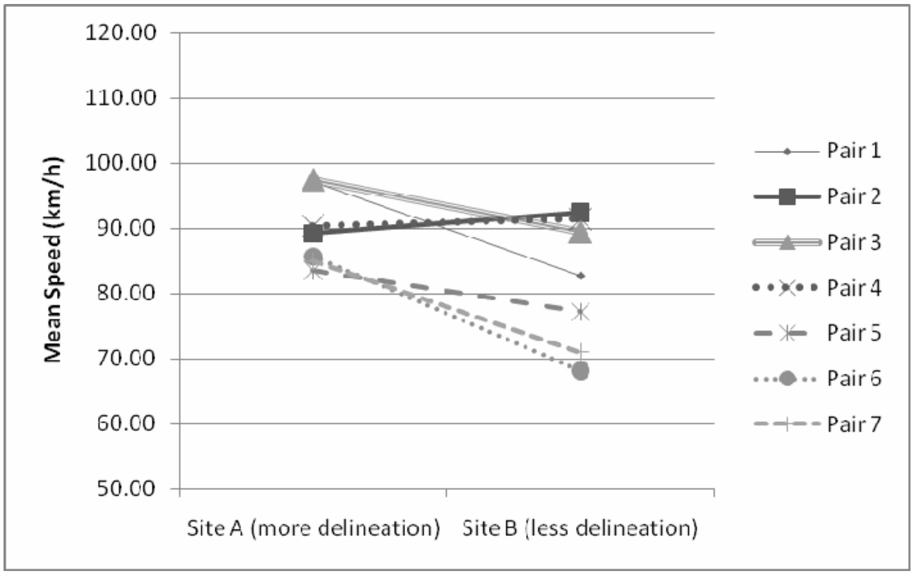

Figure 4 Average Speeds across Pairs

Sites were combined to test the effect of pavement markings on speed choice across all 14 sites. The results are summarised in Table 2.

Table 2 One-way Independent ANOVA Results for Marking Conditions

Comparison	Mean speed difference (range across six random samples, km/h)	Significance: Alpha value	95% Confidence Interval of difference (average lower and upper bounds)
Edgeline + Centreline vs Centreline Only	7.2	<0.001	6.0 →8.4
Centreline vs No Markings	13.7	<0.001	12.0 → 15.5

The results in Table 2 show that the mean free speed was greater at sites with more delineation. The differences in speed frequency distributions are shown in Figure 5.

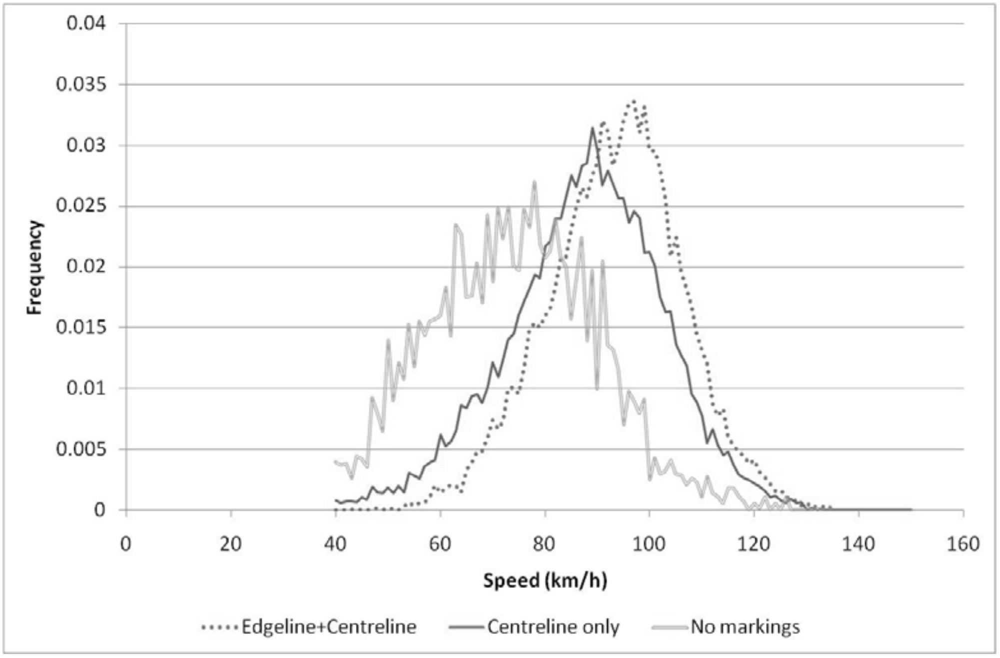

Figure 5 Relative Speed Frequencies on Rural Roads

Pavement Marking Effects: Width Investigation

The comparison above between sites of differing marking conditions did not take road width variability into account. Within pairs, sealed carriageway width varied up to 0.5m. Across all sites, this width varied from 5.5m to 7.25m, a range of 1.75m. As sealed carriageway width is a factor known to affect speed choice, it is important to take account of this in analysis. The total carriageway width, including unsealed shoulder, was not measured (as discussed in the Methods section above).

To separate width effects, sites were divided into two groups based on width. Width among pairs 1 to 4 ranged from 6.75m to 7.25m. Width among pairs 5 and 6 ranged from 5.5m to 6.0m. The seventh pair was excluded as widths in this pair were narrower than 5.5m. Any speed difference comparison within the pairs grouped by width is less likely to have sealed carriageway width as a contributing factor, than is analysis of all 14 sites together. Figures 6 and 7 below show speed distributions for different marking conditions, for different road width ranges.

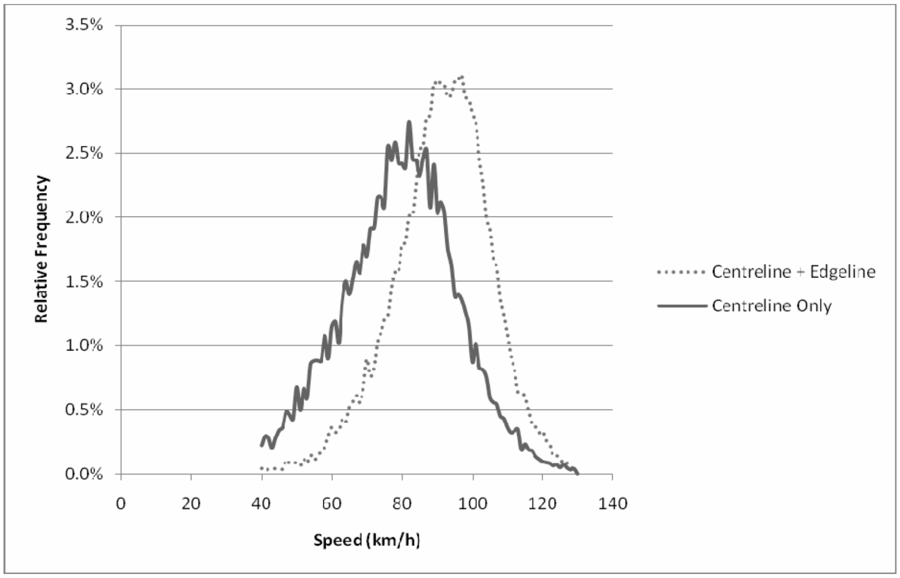

Figure 6 Speed Distribution: Road width 6.75 – 7.25m

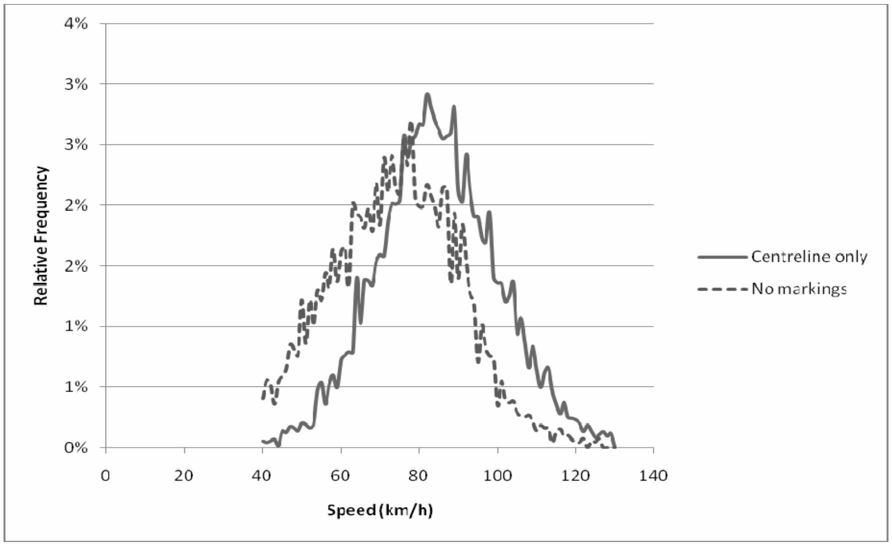

Figure 7 Speed Distribution: Road width 5.50 – 6.00m

The above figures show that the difference in speed between pavement marking conditions remains when road width is taken into account. The significance or otherwise of this difference was tested in SPSS using one-way ANOVA. The results are displayed in Table 3.

Table 3 One-way Independent ANOVA Results for Marking Conditions, Grouped by Carriageway Width

Comparison	Mean speed difference (range across six random samples, km/h)	Significance: Alpha value
Edgeline + Centreline vs Centreline Only, Carriageway Width 6.50m to 7.0m	= 93.5 → 89.0 = 4.5km/h	<0.001
Centreline vs No Markings, Carriageway Width 5.50m to 6.0m	= 84.6 → 72.1 = 12.5km/h	<0.001

The results in Table 3 show that given carriageway width variation of up to 0.5m, the mean free speed was greater at sites with more delineation.

CONCLUSIONS

This research has highlighted that the presence of centrelines and edgelines on straight rural roads affects speed. The study showed a mean speed increase of 4.5km/h on roads with centreline and edgeline, compared to roads with a centreline only. An increase of 12.5km/h was shown on roads with a centreline, compared to no markings at all. While there were inevitably other differences (between sites) which may have contributed to the speed distribution, the study method (matched pairs) took into account many known objective factors affecting speed choice, for example road geometry and sealed carriageway width.

As the safety benefits of centrelines and edgelines are not quantitatively clear, benefits from their absence may be implied from this research in terms of reduced speeds. It is suggested that rural road guidelines are amended such that pavement markings (edgelines and centrelines) be implemented only where a quantifiable safety benefit from their introduction can be confidently expected. Furthermore, while this research does not prove any particular theory of driver behaviour, it supports provision of a road environment consistent with driver expectation. Further research into the mechanisms behind driver speed choice would be beneficial, as would ongoing collaboration between psychologists and engineers working towards improved safety on our roads.

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