Effectiveness of transverse road markings on reducing vehicle speeds

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An important note for the reader

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Abbreviations and acronyms

AADT:	annual average daily traffic
ANOVA:	analysis of variance
DfT:	Department for Transport (UK)
EEM:	*Economic evaluation manual*
HCV:	heavy commercial vehicle
MoT:	Ministry of Transport
MOTSAM:	*Manual of traffic signs and markings*
NZTA:	NZ Transport Agency
SH:	State Highway
TNZ:	Transit New Zealand (now merged with Land Transport New Zealand to form the NZ Transport Agency)
UK:	United Kingdom

Contents

Executive summary

Speeding is a significant cause of safety problems on New Zealand roads. As speed mitigation measures, road signs and markings are the most cost-effective and widely implemented, but the abundance of signs being used has created a clutter effect, reducing their effectiveness. Alternative devices, whereby the road layout and its associated features can subconsciously inform a driver of the upcoming road conditions, are desired. One such device identified in overseas trials and studies is the speed perceptual countermeasure, transverse road marking.

Transverse road markings can be defined as a series of marked (either flat or raised) transverse bars placed across the road in the direction of traffic flow. They are used to assist in raising driver awareness of risk through perceptual optical effects, thus encouraging drivers to reduce their speed in anticipation of an upcoming hazard. The purpose of this report, undertaken in 2008–2010, was to establish an understanding of how transverse road markings affect driver behaviour and speeds in varying environments, and how they can be applied to reduce risk from speeding on hazard approaches in a New Zealand context. This was achieved by undertaking a literature review, and developing and applying a transverse road marking arrangement at two New Zealand field trial sites.

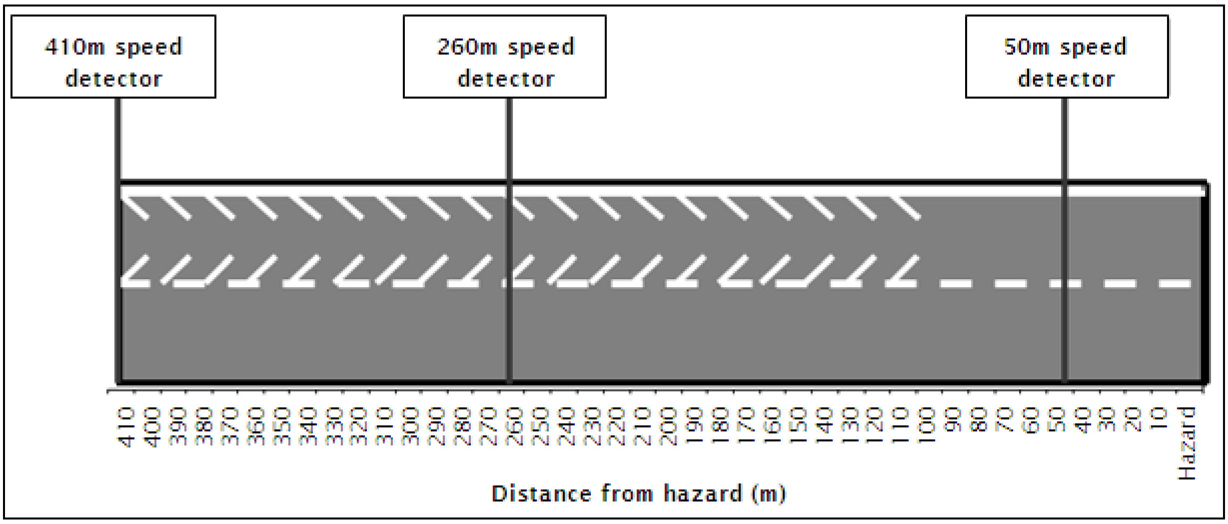
A review of available national and international literature identified that transverse road markings could be beneficial as a speed mitigation device. Reductions in mean and 85th percentile vehicle speeds were typically observed on hazard approaches after the implementation of a variety of different transverse road marking arrangements. In addition, some studies found a reduction in accident levels at the hazard itself.

No specific mention of transverse road marking was found in New Zealand legislation, design guidelines or standards, and no transverse road marking arrangement has been applied in New Zealand prior to this project. However, marking arrangements trialled within driving simulators have shown promise for applications in high-speed rural environments. In the United Kingdom (UK), the primary user of this device, a logarithmically decreasing arrangement has been applied to some motorway roundabouts and off-ramp slips. Transverse markings have also been assessed in Australia on approaches to rural intersections through field trials and driving simulators. This research found that constantly spaced arrangements could display similar speed reduction properties to those of their UK counterparts. As New Zealand's infrastructure typically lacks the large-scale motorway facilities seen in the UK, transverse markings appear to present a greater opportunity to reduce fatal and serious injury crashes caused by speeding on rural hazard approaches, including those leading up to bridges and intersections.

A methodology for two field trials was developed. It was determined that providing continuity between the field trial methodology and previous New Zealand research would be beneficial. A modified marking arrangement (figure ES1) was adopted:

- Line arrangement: 100mm transverse bars extending at a 60° angle over 1.0m from the edgeline and centreline
- Line spacing: Transverse bars placed at an even 3m spacing for approximately 300m, ending 110m prior to the hazard
- Line colours: White reflectorised road marking in accordance with NZ Transport Agency specifications
- Evaluation: A before-and-after assessment of vehicle operating speeds travelling towards each trial site hazard using a four-second headway. Speeds assessed at three locations within the hazard approach for seven continuous days two weeks prior to, two weeks after and six months after the installation of the marking treatment

Figure ES1 Visual concept of adopted layout and speed detector locations



Two transverse road marking trial sites were established in high-speed rural environments, where a reduction in speed is required to safely negotiate the following hazards:

- the southbound approach to the Kimberley/Arapaepae Road intersection on State Highway 57 (SH57)
- the eastbound approach to the Waihenga River Bridge on State Highway 53 (SH53).

Table ES1 shows the short- and long-term vehicle speed results. The significance of the mean speed changes was assessed using a full-factorial univariate analysis of variance (ANOVA) with a 95% confidence interval.

The mean and 85th percentile speeds decreased at both treatment sites as vehicles approached either the bridge or intersection hazard. This occurred whether the transverse lines were installed or not. Regardless of the variation between the short- and long-term speed changes, the main effects of the markings were to reduce vehicle speed at the start of the treatment, 410m from the hazard. Consequently, one can assume that the transverse lines have created an alerting property; drivers have reacted to the markings as they are first observed and have entered into the marking treatment at a lower speed out of precaution. Excluding the long-term result found at SH57, vehicle speeds in the short- and long-term were at levels similar to those recorded pre-installation at the midpoint of both marking treatments. It is possible that during the first 150m of the treatment, drivers became accustomed to the presence of the lines and exhibited a habitual response. Based on the long-term speed data, 50m from each hazard, it was found that vehicles arrive at lower speeds than they did prior to the installation of the lines. One possible reason for this is that the heightened perception of risk induced upon entering the marking treatment better prepared drivers to identify the visual cues associated with either the bridge or intersection hazard.

In addition to the overall speed results, ANOVA was used to determine whether any variations in the speed change trends were present between the weekday/weekend periods. In this way, it would be possible to estimate if the markings were more influential on commuter (weekday) or occasional (weekend) drivers. The speed change trends were also reviewed for light and heavy vehicles to see if the markings had varied effects on drivers of different vehicle classes. The analysis concluded that the change in mean vehicle speed was unrelated to either of the two factors. Transverse markings had the same effect on both commuter and occasional drivers travelling through the treatment. Likewise, the markings had the same effect on drivers of either light or heavy vehicles.

Table ES1 Overall speed results for each trial site

Period	Statistic	Distance from hazard		
		410m	260m	50m
SH57 Arapaepae Road/Kimberley Road intersection				
Before installation	Mean speed (km/h)	91.0	80.6	56.0
	85th percentile (km/h)	103.3	95.0	69.4
2 weeks after	Mean speed (km/h)	89.7	80.0	57.6
	85th percentile (km/h)	102.2	94.7	69.9
Short-term speed change	Marginal mean speed (km/h)	-1.3*	-0.6	1.6*
	85th percentile (km/h)	-0.8*	-0.3	0.5*
6 months after	Mean speed (km/h	87.1	77.8	53.2
	85th percentile (km/h)	100.0	92.5	67.1
Long-term speed change	Marginal mean speed (km/h)	-3.9*	-2.7*	-2.8*
	85th percentile (km/h)	-3.3*	-2.5*	-2.3*
SH53 Waihenga River Bridge				
Before installation	Mean speed (km/h)	82.3	82.3	78.8
	85th percentile (km/h)	97.4	96.5	90.8
2 weeks after	Mean speed (km/h)	79.7	83.1	78.6
	85th percentile (km/h)	94.5	97.2	91.6
Short-term speed change	Marginal mean speed (km/h)	-2.6*	0.9	-0.2
	85th percentile (km/h)	-2.9*	0.7	0.8
6 months after	Mean speed (km/h	70.1	83.5	70.7
	85th percentile (km/h)	94.2	99.7	84.6
Long-term speed change	Marginal mean speed (km/h)	-12.2*	1.2	-8.1*
	85th percentile (km/h)	-3.2*	3.2	-6.2*

*speed change is statistically significant

The literature review and field trials demonstrated that transverse road markings could be used as a practical speed mitigation device on high-speed, rural hazard approaches in New Zealand. Statistically significant mean speed reductions were determined at intervals within the transverse marking treatment. Consequently, it is recommended that further trials be conducted to allow for more accurate and empirical evidence to be collected. This will allow a standardised procedure for transverse road marking in New Zealand to be formalised. If these trials are undertaken, consideration should be given to methodological improvements, such as a reduction of the treatment length, and of the distance between the start and finish of the markings prior to the hazard. More visually pronounced lines may also increase the size of the speed reduction. This could be achieved by increasing the widths of the transverse bars to around 500mm and by increasing the spacing gap.

In summary, the overall success or failure of transverse road markings as an accident prevention measure should not be purely based on the changes in vehicle speed. Because of the limited time available for this trial, the hypothesis that a positive relationship possibly exists between reduced travel speed and a reduction in speed-related crashes has been assumed. The markings' effect on safety through a reduced accident history will be a more telling statistic to judge their overall effectiveness by.

Abstract

Transverse road markings as a speed mitigation device may be a cost-effective method of reducing fatal and serious injury crashes as a consequence of speeding on a high-speed hazard approach. As no established marking layouts have been formally applied in New Zealand, investigations into the use and application of transverse road markings have been conducted over 2008–2010. The culmination of this research was to develop and undertake two field trials on the New Zealand State Highway network.

The field trials assessed vehicle speed in a before-and-after study. Vehicle speed was recorded two weeks prior to, two weeks after and six months after the installation of a 300m long transverse bar arrangement, starting at a distance of 410m from a high-speed rural hazard. It was found that the markings reduce vehicle speeds, particularly upon the entrance into the marking treatment. This trend was found to occur both in the short and long term. Based on these results, it was recommended that further trials be conducted with a slightly modified marking arrangement and a larger assessment period. The results of the trials conducted as part of this paper will contribute to the formalisation of a standardised procedure for transverse road marking in a New Zealand roading environment.

1. Introduction

1.1 Background

Speeding, either travelling over the speed limit or driving too fast for the conditions, is a significant cause of safety problems on New Zealand roads. A simple indication of the magnitude of this issue is the number of speed related crashes contributing to New Zealand's road fatality toll. On average, between the years 2006 and 2008, speeding on open roads was a factor in 22% of all fatal road crashes in New Zealand (Ministry of Transport (MoT) 2009). These crash trends are not unique to New Zealand roads. Speeding is one of the dominant causes of fatal road crashes worldwide. In the United States, for instance, 31% of all fatal road crashes note speeding as a contributing factor (National Highway Traffic Safety Administration, 2007). Consequently, the research, development and implementation of speed mitigation devices continue to be emphasised both in New Zealand and overseas (eg Charlton and Baas 2005).

Speed mitigation devices include signage, road markings and variable message systems. Typically, they are placed in advance of an upcoming hazard, with the aim of initiating a change in driver behaviour. In particular, signage and markings are widely used for the purposes of explaining road layouts and hazards because of their relatively minor costs in comparison to altering existing geometric layouts.

However, an issue currently occurring in some locations, both in New Zealand and internationally, is that the number of road signs being used has created a clutter effect. Consequently, drivers are confronted with too many signs to comprehend, limiting the impact of the signs and their and ability to modify driver behaviour. The need for alternative speed mitigation devices that can subconsciously inform a driver of the upcoming road features is highly desired. One such device identified in overseas trials and studies as having the potential to achieve these goals is the speed perceptual countermeasure, transverse road marking.

1.2 Definition

Transverse road markings can be defined as a series of marked (either flat or raised) transverse bars placed across the road in the direction of traffic flow (see figure 1.1). They can be called varying names such as herringbone, yellow bar and Wundt Illusion markings. The markings are used to assist drivers in raising their awareness of risk through perceptual optical effects, thus encouraging speed reduction to an approaching hazard. Consequently, drivers get an increased reaction time to respond to the situation in front of them.

As a speed mitigation device, transverse road markings could present an opportunity to make a cost-effective approach for reducing the fatal and serious injury crashes that result from speeding on hazard approaches. Further investigations into the application and use of the markings in a New Zealand context have been formally conducted through the completion of this research project, which was undertaken in 2008–2010.

Figure 1.1 An example of transverse road markings

1.3 Scope and purpose

The purpose of this research is to establish an understanding of how transverse road markings affect driver behaviour, how they affect driver speeds in varying environments and how they can be applied to reduce the risks to road users created by speeding on hazard approaches in a New Zealand context. In order to achieve these aims, the project had the following objectives:

- to report on the effectiveness and application of previous transverse road marking trials both nationally and internationally
- to develop an appropriate layout and methodology for field testing in a New Zealand environment
- to conduct field trials at two locations on New Zealand roads
- to provide evidenced-based material that could aid the development of best practice guidelines and recommendations for the industry.

The research presented aligns well with the NZ Transport Agency's (NZTA's) strategic priority of improving the road safety system. In addition, it can be related back to a number of strategic directions provided by the government, namely, 'Assisting safety and personal security' within the New Zealand Transport Strategy (MoT 2008). In this way, the research has the potential to contribute to the New Zealand Road Safety Strategy 2010–2020, which endeavours to 'significantly reduce the impact of speed on crashes by reducing the number of crashes attributed to speeding and driving too fast for the conditions' (MoT 2010).

1.4 Report structure

The main body of this report is divided into a series of eight chapters. The chapters are ordered chronologically in order to reflect the progression in which the research was undertaken.

- Chapter 2 documents a review of available national and international best practice in the use of transverse road markings. It highlights the history, performance details, features and issues associated with different marking arrangements, and the environments in which they have been applied.
- Chapter 3 describes a methodology adopted for the application of transverse road marking at two trial sites in New Zealand. It also details the processes and selection criteria assumed in the assessment of prospective trial sites.
- Chapters 4 and 5 detail the analysis methods used for evaluating transverse road marking at two trial sites and the results of this analysis.
- Chapter 6 discusses the performance of the transverse road markings over the field trial analysis periods, and notes any common trends observed during and between each assessment period.
- Chapters 7 and 8 document the conclusions and recommendations resulting from this study.

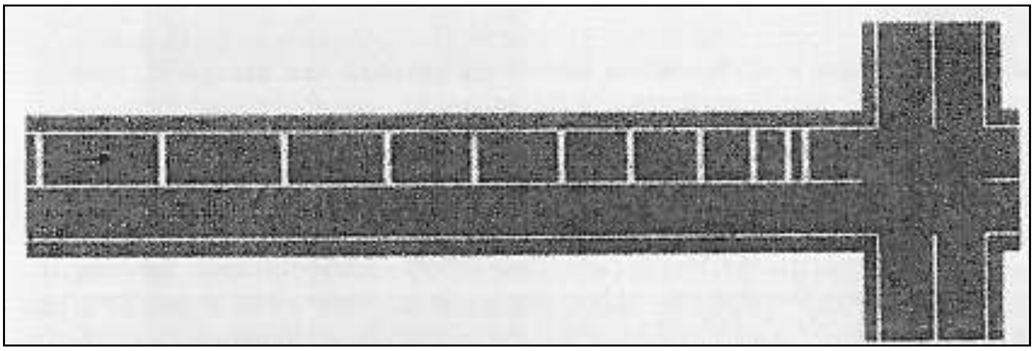
2. Literature review

2.1 Overview

A review of available national and international literature was undertaken to assess the ability of transverse road markings to act as a speed mitigation device. With reference to previously completed research trials, the literature review would help identify existing applications and known driver behaviour trends, both in New Zealand and internationally.

Transverse road markings were initially developed in the 1970s at the United Kingdom's (UK's) Transport and Road Research Laboratory. However, it is still unclear and widely debated as to how exactly these markings interact with drivers to reduce vehicle speed. At the time of initial testing, it was hypothesised that the markings would have a similar psychological effect to that of driving on narrow rural roads (Denton 1971). Consequently, a logarithmically decreasing line arrangement (as illustrated in figure 2.1) was thought to give a driver a perceived sense of acceleration through an optical illusion in the driver's visual field (Rutley 1975). To this day, various research papers have discussed whether the perceptual effects of the markings are actually the mechanism that causes the speed reduction. As an alternative, it has been suggested that the primary effect of transverse markings is to act as large warning device that is difficult for a driver to neglect (Jarvis and Jordan 1990). Under this alternate hypothesis, the markings encourage a driver to make a decision to slow down out of precaution (Burney 1977).

Figure 2.1 Logarithmically decreasing transverse marking arrangement (from Godley et al 2000)



Because of this high degree of uncertainty as to their interactive driver properties, a variety of marking arrangements and layouts have been trialled both on driving simulators and in the field. However, regardless of the mechanisms causing the change in driver behaviour, on many occasions, research has indicated that a reduction in vehicle speed can be achieved through the implementation of this device. Given the wide range of applications and the very few design guidelines that exist overseas, the methodology adopted for use in New Zealand field trials has had to consider a variety of contradictory findings. For such reasons, New Zealand legislation, design guidelines and road safety standards have also been examined as part of the literature review. Such standards help identify any restrictions that would limit the formulation of an appropriate field trial methodology.

2.2 Provisions for use of transverse road markings in New Zealand

2.2.1 Legislation

Legal requirements concerning the use of road markings in New Zealand (such as transverse road markings) are set out in *Land transport rule: traffic control devices 2004* (Land Transport NZ 2005). This rule seeks to control traffic through the application of safe, appropriate, effective, uniform and consistently applied traffic control devices such as signs, markings and traffic signals. General requirements for such devices include the need to convey a clear and consistent message to road users. Accordingly, the rule specifically permits a number of identified signs, markings and signals.

The rule does not make specific reference to the use of transverse road markings other than for stop and give way control markings. Such markings for the purpose of reducing hazard approach speeds are not incorporated into schedule 2.0 of this rule (line marking specification). However, the rule states that any markings must have one of the following functions:

- Regulatory: these instruct road users by requiring or prohibiting specified actions using the road.
- Warning: these instruct road users of permanent hazards on a roadway, or give advance notice of features on or near a road.
- Advisory: these provide road users with information or guidance in the intended use of the road.

With regards to the general requirements of road markings, the rule states that a traffic control device should contribute to the safe and effective control of traffic and must:

- be safe and appropriate for the road, its environment or the use of the road
- not dazzle, distract or mislead road users
- convey a clear and consistent message to road users
- be placed as to allow adequate time for the intended response from road users.

Consequently, it can be said that although they are not documented within existing legislation, transverse road markings appear to be consistent with the rule. As a ‘warning’ device, they would give advance notice of an upcoming hazard. For future applications in New Zealand, the device must be designed in such a manner to finish with sufficient space between the end of the treatment and the hazard to allow an appropriate driver response.

2.2.2 Standards, guidelines and policies

A review of existing New Zealand standards, guidelines and policies found no reference to the use of transverse road markings. This is consistent with the exclusion of any transverse marking noted by the Traffic Control Devices Rule (Land Transport NZ 2005). The following documents were reviewed in this process:

- *Manual of traffic signs and markings* (MOTSAM) part II: markings (Transit New Zealand (TNZ) and Land Transport NZ[1] 1994)
- *Code of practice for temporary traffic management* (TNZ 2004a)
- *Road and traffic standard 5: guidelines for rural road markings and delineation* (Land Transport NZ 1992)

1 Land Transport NZ and Transit have now merged to form the NZTA.

- *Road and traffic standard 10: road signs and marking for railway level crossings* (Land Transport NZ 2000)
- *Road and traffic standard 11: urban roadside barriers and alternative treatments* (Land Transport NZ 1995)
- *Road and traffic standard 15: guidelines for urban rural speed thresholds* (Land Transport NZ 2002).

While no mention of transverse line markings was found, it was determined that in New Zealand, the following road marking devices are placed transversely across the pavement, whether on the shoulder or across the lane:

- stop limit lines
- give way limit lines
- flush medians
- cross-hatching
- pedestrian crossings
- striped chevron shoulder markings.

2.3 Current New Zealand use and trials

2.3.1 General findings

The available literature indicated that at the time of this research project, no officially documented trials of transverse road markings had been carried out in New Zealand, although the idea had been previously proposed. However, similar applications to implement speed mitigation devices with comparable properties to those of transverse markings have been attempted. Some of the more interesting projects are described below.

2.3.2 Simulator trials

2.3.2.1 Introduction

Three trials on the use of some form of transverse road markings/perceptual countermeasures have been undertaken by TERNZ Ltd and the University of Waikato, Hamilton, New Zealand. A vehicle simulator was used to assess driver reactions to different types of road safety treatments, including varying delineation and signs. These trials were documented in three papers.

2.3.2.2 Charlton (2003)

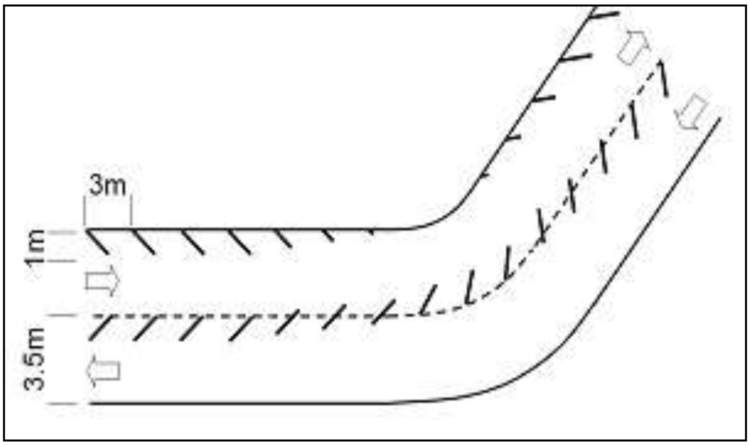
Charlton (2003) undertook a trial that aimed to evaluate a number of road safety measures in relation to a road type with specific types of crashes. In particular, transverse road markings (as illustrated in figure 2.2) were placed across the road on the approaches to intersections that had restricted sight visibility for both those entering the main road from the intersection and for through traffic. The markings extended 1.5m from the left and right edge lines, leaving a small gap in the middle of the lane with no markings, and stopped at approximately 110–140m prior to the intersection. The results concluded that at the locations tested, a marked reduction in drivers' average speeds was noted. These speed reductions were determined to be greatest during the first section of the treatment and were found to taper off after 250m.

Figure 2.2 Transverse road marking used in a simulator trial (Charlton 2003)

2.3.2.3 Charlton and de Pont (2007)

Transverse road marking, perceptual countermeasures (as shown in figure 2.3) were used as part of a research project by Charlton and de Pont (2007) investigating speed management through curves. The herringbone markings were marked prior to and through the curve (compared to the treatment in figure 2.2, where they stopped prior to the hazard). The markings were 1m wide, placed on an angle 3m apart and also provided a wider 'gap' in the middle of the lane than those identified in figure 2.2. The evaluation concluded that although no reductions in drivers' speeds were noted beyond what the curve advisory signs achieved, the markings did provide a significant change in drivers' lane positions.

Figure 2.3 Herringbone markings as part of a speed-reduction measure at curves (Charlton and de Pont 2007)



2.3.2.4 Charlton and Baas (2006)

In 2006, Charlton and Baas published a research paper that evaluated speed change or speed maintenance methods to alter driver behaviour, particularly to reduce their approach speeds to a hazard. The research included the assessment of both self-explanatory road concepts and various perceptual countermeasures. As part of the investigations, the performance characteristics of raised transverse rumble strips and transverse marked lines (such as dragon teeth, as shown in figure 2.4) were reviewed. Specifically for these two perceptual countermeasures, a reduction in average vehicle speeds of 0.1–6% and 8–14% was determined for raised transverse rumble strips and transverse marked lines (dragon teeth), respectively.

Figure 2.4 Example of dragon teeth road markings (Charlton and Baas 2006)

2.3.3 Zig-zag pedestrian warnings

Experimental markings used in Australia at pedestrian crossings were trialled in Auckland, New Zealand, between May 2004 and December 2005. The markings are situated in the centre of a lane, providing a greater visual response than the existing diamond marking that is currently in use in New Zealand. The visual response of the road markings allows greater physical awareness of the approaching hazard and creates a perception of a change in environment.

The zig-zag pattern is installed over 50m from the pedestrian crossing and is predominantly applied in urban environments such as around schools. Although the markings provided no conclusive evidence of safety improvements in the Auckland trials, they were deemed not to worsen the safety performance of the crossings either (NZTA 2010a). A similar version of the road markings used in New South Wales, Australia, can be seen in figure 2.5.

Figure 2.5 Zig-zag pedestrian warning in Australia

2.3.4 Transverse markings

2.3.4.1 Horowhenua District

Transverse road markings were applied to Tararua Road on both approaches to State Highway 57 (SH57) in the Horowhenua District. In this rural environment, Tararua Road typically has high vehicle approach speeds prior to the crossroads intersection. A number of fatal crashes were recorded at the intersection, caused by drivers failing to give way at the stop sign controls. Unfortunately, limited official information is available regarding why they were installed, what standards were used and whether any evaluation has been undertaken. It is unknown whether the markings or redesign of the intersection contributed to a changing crash history at the intersection. It is difficult to make any noteworthy conclusions on their effectiveness, given the limited information available.

2.3.4.2 Rotorua District Council – transverse markings proposal

One documented application to use transverse markings as a hazard warning device was completed by Opus International Consultants on behalf of the Rotorua District Council in January 2008 (TNZ and Rotorua District Council 2008). The proposed installation site was on the northbound approach to the one-lane Mangapouri Bridge (SH36, route position 8/5.75). The Rotorua District Council had received numerous reports of near misses or incidents when vehicles travelling in the northbound direction across the one-lane bridge had not given way as required. In addition, on-site observations showed the approaching vehicles did not reduce speed before the bridge. Transverse markings were recommended as a possible treatment option. The markings were designed using the guidelines listed in the UK's *Traffic signs manual 2003* (Department for Transport (DfT) 2003). This specific application was rejected by TNZ, who, at the time, determined the markings were an unjustified treatment option for the site.

2.4 Provision, use and trials internationally

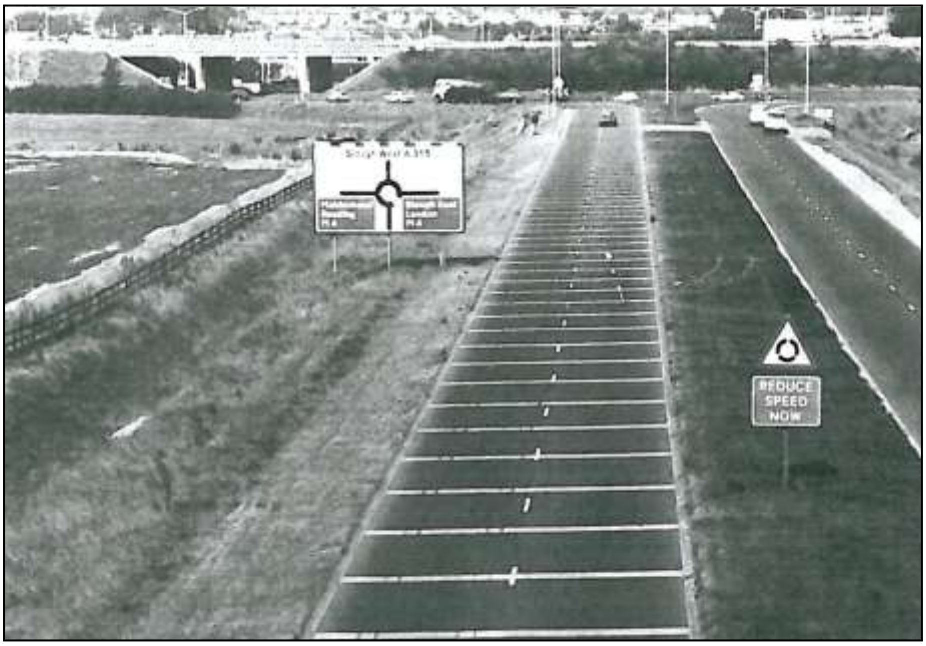
2.4.1 United Kingdom

The use of transverse road markings or 'yellow bar markings', as they more commonly referred to in the UK, is widespread. Since their original development at the Transport and Road Research Laboratory, transverse road markings have been thoroughly investigated and implemented in the UK as a speed treatment option for motorway roundabouts and motorway slip-roads. These areas are noted for the high speed changes required to navigate the approaching intersection hazard safely.

In the documented cases available, DfT Standard TD6/79 (Department for Transport 1986) has always been used, allowing a high level of consistency between the analyses of different UK sites. The TD6/79 standard is adopted within the DfT design guidelines (2003) as the recommended pattern for transverse markings on roundabouts and motorway slip-lanes. The TD6/79 pattern generally has 90 yellow transverse bars on main carriageways and 45 on slip-roads, installed in a logarithmically decreasing arrangement. The bars are 600mm wide and installed at right angles to the centre line of the carriageway, encompassing the entire lane width in the direction of travel. The final bar that will be driven over is laid 50m in advance of the 'give way' line (DfT 2003). As the markings are not prescribed in the DfT's *Traffic signs regulations and general directions* (DfT 2002), written authorisation from the Secretary of State is required for each site where it is proposed that they will be used. An example of this TD6/79 arrangement can be seen in figure 2.6, where transverse markings have been applied to a site in Windsor.

The field performance of this specific bar pattern arrangement has been critically assessed in the UK through a number of variables such as speed reduction (Denton 1971), driver behaviour (Burney 1977) and accident reduction (Helliar-Symons 1981; Haynes et al 1993). The studies all gave positive performance reviews and transverse markings will continue to be used where they are deemed to meet the criteria detailed in guideline 11.3 of the DfT (2003). In the research available, no improvements or modifications to the yellow bar layout was trialled or recommended. The research available was primarily aimed at understanding the markings' effects on drivers, and displaying before and after speed and accident assessments.

Figure 2.6 Yellow bar markings in the UK on approach to a roundabout (Helliar-Symons 1981)



2.4.2 Australia

Of the most current Australian standards, guidelines and policies reviewed, only a small reference is made to the use of transverse road markings. The Austroads *Guide to traffic management: part 6* (2007) notes the potential use of this device as a speed reduction tool on the approach to roundabouts:

> *Whilst the reduction in speed should be achieved through appropriate design of the roundabout approach, at sites where there is a problem with drivers approaching at excessive speeds it may be necessary to employ traffic management measures to assist in speed reduction. Treatments may include...: pavement markings across the road...The effectiveness of all of these treatments, including the provision of reverse curves, is not completely known.*

Little information is available in regard to the exact specifications or designs that have been adopted by Australian road designers. In addition, few examples of this device could be identified in operation. However, from aerial photography, it appears that isolated examples of transverse markings do exist. The layouts installed look similar to those used in the UK, as can be seen in figure 2.7, where transverse road markings have been placed at a roundabout approach on the Pacific Highway, New South Wales. It is noted that the transverse bars are white in colour, meeting the Austroads specifications of line marking guidelines (2009a).

Figure 2.7 Transverse road markings used as a speed deterrent from a 100km/h to 70km/h speed zone on the Pacific Highway in New South Wales, Australia (photo courtesy of Google Earth Pro License)

Although transverse road markings are not widely implemented In Australia, extensive research into their effects and performance has been undertaken. The research has included the use of driving simulators (Godley et al 2000) and live field trials in Victoria (Jarvis and Jordan 1990). These research projects investigated the performance of transverse road markings as a speed mitigation device on approaches to rural intersections. Typically, the UK 'yellow bar' pattern was used; however, a number of distinct variations were tested. Such variations included the use of constant bar spacing and the use of peripheral squares protruding 60cm from the edgeline as opposed to full transverse bars (Godley et al 2000).

All of the research indicated that the markings (no matter the layout) do achieve some form of speed reduction, although this reduction was relatively minor (approximately 5km/h). Both papers concluded that this was not a result of the decreased bar spacing but was caused by the initial alerting properties of the device. Godley additionally determined that speed reduction occurring in the later stages of a treatment area is a result of the peripheral properties of the lines.

2.4.3 Other

No specific legislation or design guidelines for transverse line markings were found in other guidelines such as:

- US Department of Transportation *Manual on uniform traffic control devices* (Federal Highway Administration 2003)
- British Columbia *Manual of standard traffic signs and pavement markings* (Ministry of Transportation and Highways 2000).

However, transverse markings have been further investigated as a speed countermeasure by researchers at various institutions (e.g. Vest and Stamatiadis 2005). As the markings used have not been based on specific legislation or guidelines, the device arrangements, alignments, applications and methods are wide-ranging.

Primarily the literature reviewed from the United States concentrated on the application of transverse markings on sharp horizontal curves (eg Storm 2000). In most applications, transverse markings saw minor speed reductions when evaluated in before-and-after studies. The markings were either applied prior to the point of curvature or through the curve (eg Gates et al 2007).

2.5 Trends identified

2.5.1 Application

The research available has typically been conducted in areas where an approaching hazard is required to be taken at a reduced speed, thus minimising the potential for a high-speed crash to occur. These hazards have come in the form of intersection approaches, motorway off-ramps, bridge approaches and high-speed curves. Primarily, these high-speed areas are located on open rural roads where the surrounding road environment does not vary distinctively in terms of colour or contrast, as is the case in an urban environment (Godley et al 2000).

2.5.2 Layouts implemented

2.5.2.1 General notes

A wide variation in the layout types of transverse marking have been trialled. In the most part, the layouts developed have depended on the specific application and country in which they were applied. Much of the differences have arisen from the individual goal of the researcher of the time. The following sections give a description of the variations used for the colour, spacing and arrangement of the different line markings layouts used.

2.5.2.2 Line colours

The line colours used for the markings are usually either white (eg Gates et al 2007) or yellow (all applications in the UK). No reference is made in the standards and literature reviewed to indicate why these colours have been chosen for transverse road markings. It is most likely that the colours are determined by the statutory requirements for line marking in the country where the trials have occurred. Research into the effect of speed zones defined by specified line marking colour has been investigated (eg Selby 2006). The Netherlands is the only country known to use different line colours to distinguish between speed zones (eg a 100km/h speed zone can be indicated by a green line between two white lines in the centre of the road). This Dutch system would allow speed changes to be easily recognisable. If transverse road markings are to be widely implemented in New Zealand, white lines are likely to be used so as to be consistent with the existing standards on rural roads for edgelines and centrelines (e.g. those given in MOTSAM).

2.5.2.3 Line spacing

Most research projects have adopted a line spacing similar to the original logarithmic patterns developed at the Road Research Laboratory in the 1970s. The general pattern sees the line spacing logarithmically decreasing on the approach to the hazard, as can be seen in figure 2.1. Internationally, this form of line spacing has been the most widely tested and applied to all types of hazards, including the approach to high-speed horizontal curves (eg Storm 2000). The physical dimensions adopted by this arrangement are detailed in the DfT *Traffic signs manual* (2003).

As a result of the hypothesis determined by researchers such as Jarvis and Jordan (1990), it was acknowledged that the line layouts could also be equally spaced. Empirical results from simulator trials have confirmed that evenly spaced bar arrangements also display speed reduction properties (eg Charlton 2003). No field trial of this even spaced form was found in the available literature.

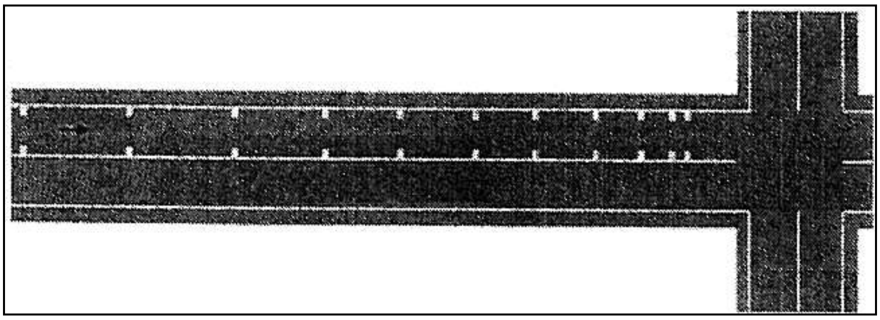
The distance between the final line and the hazard has also varied between different sites. No two hazard types are the same; therefore, one standard cannot be applicable for all circumstances. The UK TD6/79 standard (DfT 1986) arrangement places the final bar at a distance of 50m from the hazard. In contrast, when other marking arrangements have been adopted, the final bar has been placed anywhere between 35m (Jarvis and Jordan 1990) to 110m (Charlton 2003) from the hazard.

2.5.2.4 Line arrangement

The most common arrangement internationally saw transverse lines laid fully across the direction of travel from edgeline to edgeline. Common disbenefits with this approach were the upward costs involved with maintenance, the perception of decreased skid resistance on the road surface and, in particular, difficulties for motorcyclists to handle driving over them in wet conditions.

Research has also shown that alternative forms of the transverse line arrangements have been proposed. In the simulator experiments undertaken at the Monash University Accident Research Centre, for example (Godley et al 2000), a peripheral arrangement, as seen in figure 2.8, was tested. The squares are 600mm from the boundary and give the driving line a minimum width of 2.5m of unpainted area in the middle of the lane. As with the line arrangement proposed by Charlton (as seen in figure 2.2), a number of benefits can be derived from these types of arrangements, in terms of application, maintenance costs and the limited effect on skid resistance. Simulator trials have determined that this type of arrangement can perform just as successfully as their full-lane counterparts (Godley et al 2000).

Figure 2.8 An alternative to full edgeline-to-edgeline bars (Godley et al 2000)



A similar arrangement was also adopted in American trials for a high-speed freeway curve in Milwaukee (Gates et al 2007). This trial used 18-inch by 12-inch (457cm by 305cm) squares that were placed on the edgelines to create the peripheral speed illusion, as can be seen in figure 2.9. In this case, the squares were applied at a decreasing rate 500 feet (152.4m) prior to and after the curve centre. The results from the curve were similar to those encountered by Godley in that speeds seemed to be reduced.

Figure 2.9 Example of high-speed curve layout (Gates et al 2007)

2.5.3 Methodologies used

Research undertaken on driving simulators typically involved a small number of participants being exposed to a series of different treatments in a virtual, computer-generated environment (eg Godley et al 2000). The response of participants to the visual stimuli (with the use of a steering wheel and foot pedals) allowed the monitoring of representative speed and acceleration/deceleration patterns. Comparisons between virtual speeds in a control and transverse line marking scenario were typically compared for the same hazard approach. In this way, the speed reduction properties of a transverse marking treatment could be estimated.

A large majority of research projects involving field trials monitored the success of their transverse marking application by undertaking before-and-after speed studies (eg Vest and Stamatiadis 2005). The length of time between before and after periods varied considerably between projects. Short-term analysis generally ranged between one week to one month after installation (Denton 1971), while long-term results ranged between 6 to 12 months after installation (Gates et al 2007). Speed was assessed by devices including air tubes, metal strips and radar speed meters, often at more than one interval within the line marking treatment (eg Jarvis and Jordan 1990).

As mentioned earlier, crash reduction monitoring has also been carried out in the UK. The 'after' sections of the before-and-after crash studies were typically assessed one to two years after installation (eg Haynes et al 1993).

2.5.4 Transverse marking performance

Research studies have indicated that traverse marking can cause a reduction in vehicles' operating speeds (eg Vest and Stamatiadis 2005). This trend has been found to occur for both the mean and 85th percentile speeds. Results of trials identified in the literature review are documented in table 2.1.

In many instances, the markings resulted in much higher speed reductions in the period immediately following installation that lessened over time (eg Gates et al 2007). This trend could be attributed to a 'novelty effect'. That is, because of the regularity at which individual drivers travel through the hazard approach, the markings may become less effective over time.

The success of transverse road markings will ultimately be judged on the effect that they have on a crash record at a given site (Denton 1971). Analysis in the crash performance of roundabouts (Helliar-Symons 1981), motorway slip-roads (Haynes et al 1993) and horizontal curves (Agent 1980) after transverse markings have been implemented has shown a high reduction in the percentage of speed-related crashes. These findings are summarised in table 2.2.

Table 2.1 Speed reduction examples measured in transverse marking trials

Researcher	Year	Location	Application	Results
Denton	1971	UK	High-speed approach to roundabout on M8 motorway	Mean and 85th percentile speed reductions of over 20% (~10–20km/h) one month after installation
Agent	1980	USA	High-speed horizontal curve on US-60 highway	Average speed reduction of 12.3mph (~20km/h). Percentage of drivers over the rated speed limit decreased by 50%.
Jarvis and Jordan	1990	Australia	High-speed approach to rural intersection	Mean speed reductions of 2–5km/h
Godley et al	2000	Australia	High-speed approach to rural intersection (simulator: full lines)	Mean speed reduction of 9.26km/h through treatment site
Godley et al	2000	Australia	High-speed approach to rural intersection (simulator: squares)	Mean speed decrease of 6.61km/h through treatment site
Charlton	2003	New Zealand	High-speed approaches to intersection (simulator)	Marked reduction in drivers' average speeds
Charlton and Baas	2006	New Zealand	Variety of measures and environments (simulator)	Reduction in average speeds of 0.1–6% for raised transverse markings and for transverse marked lines (dragon teeth) of 8–14% and 2.1–13.7%
Charlton and de Pont	2007	New Zealand	High-speed approaches to and through curves (simulator)	The results for the reduction in drivers' speeds were insignificant; however, they also showed significant changes to the drivers' observed lane positions.
Gates et al	2007	USA	High-speed freeway curve	High initial reduction lessened over six months to 3.7mph (5.92km/h) approximately halfway into the treatment section.

Table 2.2 Crash data from available transverse marking literature

Researcher	Year	Location	Application	Results
Denton	1973	UK	High-speed roundabout approach	Fourteen accidents in the year before; two in the 16 months after implementation
Agent	1980	USA	High-speed horizontal curves	Eight crashes per year in the six years before; three crashes in the year after installation
Helliar-Symons	1981	UK	High-speed roundabout approach	A 57% reduction in speed-related crashes for the 42 roundabout approaches with transverse markings
Haynes et al	1993	UK	High-speed motorway slip lanes	A crash reduction of between 11% and 18% on 48 test sites. Results considered not to be statistically significant

Whether these crash benefits can be replicated at other hazardous locations such as bridges and rural priority controlled intersections has not been described in the research papers available for review. However, it would be fair to assume that the influences of transverse markings, whether through heightened driver awareness or through subconsciously affecting a driver's decision to reduce speed, may improve the safety performance for a range of hazardous locations.

2.5.5 Driver behaviour

As indicated in the speed or crash performance, the application of transverse markings has an effect on driver behaviour, generally through the decrease in the perception–reaction time of hazards ahead (Godley et al 2000). However, a major concern, as with other safety devices, is the need to reserve this device for the most appropriate locations only. It was determined that a driver's approach to the marking layout had a strong correlation with their previous experience with similar types of markings (Burney 1977). That is, a driver's assessment of a new site will be predetermined by his or her individual past experience of the location and its markings. Therefore, the exact nature of the application site must be appropriately considered as being hazardous or it will risk being counterproductive.

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3. Field trial methodology

3.1 Outline

Following the literature review, a methodology for the implementation of transverse road markings at two New Zealand field trials was written and developed in association with the NZTA and relevant experts. The empirical results obtained from the trials will be used as a starting point for any future investigation into the application of these markings in New Zealand and assist in the development of best practice guidelines, providing recommendations for their use in the industry.

The primary objective for the two trials was to assess the speed of vehicles travelling towards a hazardous location in a before-and-after vehicle speed evaluation. A direct assessment of accident prevention could not be undertaken as part of the trial analysis because of the limited time and, as a consequence, crash data that would be available. For this reason, the trials had to assume a positive relationship between reduced travel speed and a reduction in speed-related crashes.

Through discussions with the NZTA, it was determined that it would be beneficial to provide continuity between this methodology and previous New Zealand research undertaken by Charlton (2003). For such reasons, a similar marking arrangement to Charlton's was adopted. The markings were required to be customised in order to be more conservative. This approach was taken after concern was raised that the layout may be too radical for New Zealand drivers to comprehend.

The trial methodology considered variables that were critical in the design of this specific transverse line marking arrangement. These variables were consistent with those identified during the literature review, namely:

- application and location
- line arrangement
- line spacing
- line colours
- evaluation.

An overview of each method variable is described in greater detail within the remaining sections of this chapter.

3.2 Application and location of field trials

3.2.1 Application

An extensive investigation of potential trial sites was undertaken to determine two locations that would maximise the benefits of the trial markings. Based on the different arrangement designs seen during the literature review, the following characteristics were considered ideal for a rural application. These are sites where:

- a reasonable reduction in speed is required to safely negotiate a hazard
- the hazard a long straight approach prior to it
- no extensive speed treatments have been implemented

- no existing speed mitigation features are present that could affect the performance of the markings (eg flush medians, striped shoulders or changes in posted speed limits)
- a noteworthy crash history where excessive speed is or could be a potential problem.

To fit these selection criteria, the type of rural hazards deemed appropriate included roundabouts, priority and uncontrolled intersections, and bridges and curves. As the trial aimed to be conservative, thereby minimising potential risk, applying the markings through corners was not considered feasible.

Sites achieving all desirable characteristics proved difficult to locate. In particular, it was found that long, straight sections in excess of 400m prior to a hazard were unusual. In addition, it was found that sites identified as having a crash history tend to be well known within the roading industry and often already had several treatments in place or were in the process of a safety review. In spite of these challenges, two sites were selected for trial, one near Levin on the Kapiti Coast, and one between Featherston and Martinborough in the Wairarapa.

3.2.2 Location

3.2.2.1 Kimberley/Arapaepae Road intersection

The intersection is located near Levin on State Highway (SH) 57 (route position 0/2.083), approximately 2km to the east of SH1 (see figure 3.1). The intersection is arranged as an out-of-context curve, with SH57 traffic having priority. This effectively allows the northbound left-turning Kimberley Road traffic and southbound right-turning Arapaepae Road traffic to travel through the intersection, as can be seen in figure 3.2.

The southbound approach of Arapaepae Road is approximately 500m in length (following a high-speed curve) and has a posted speed limit of 100km/h. On the approach to the intersection, a major reduction in speed is required by southbound traffic to negotiate the intersection safely. The site has an approximate two-way annual average daily traffic (AADT) volume of 4450 vehicles (NZTA count site ID:05700002), 11.3% of which comprises heavy commercial vehicles (HCVs).

A review of the NZTA crash database noted that 15 crashes occurred at the intersection between 2004 and 2008. Six of the 15 crashes were caused by drivers travelling too fast on the southbound intersection approach and then losing control when making the right-hand turn. One crash was attributed to losing control at excessive speed on the southbound approach when making a left-hand turn at the intersection.

At the time of the investigation, no speed advisory signs are placed along the southbound approach or indicate the reduction in speed that is required for the turning movements left or right. The only existing signs in the area are the advanced directional signs located approximately 250m from the intersection and the intersection directional sign positioned at the intersection. Edgeline rumble strips have been placed over the trial length on both sides of the carriageway. They end approximately 50m prior to the intersection but were not expected to affect the performance of the road marking trial. The rumble strips were present both before and after the transverse markings were installed. A small number of rural properties have driveway accesses onto both sides of Arapaepae Road along the site length. However, the operation of the driveways is not expected to have a significant effect on through speeds during the trial.

Additional images of the trial site have been included within appendix A. They provide an overview of the southbound intersection approach and document the trial site before and after the road markings were implemented.

Figure 3.1 Location of the Kimberley/Arapaepae Road trial site (image courtesy of Google Earth Pro Licence)

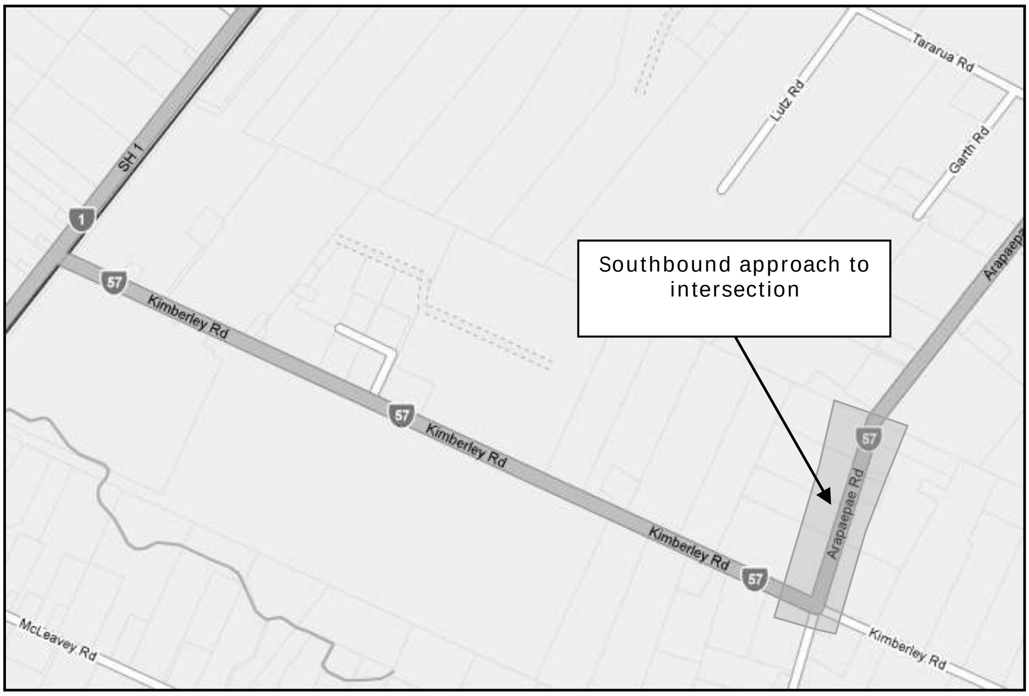


Figure 3.2 Southbound approach to the Kimberley Road/Arapaepae Road intersection

3.2.2.2 Waihenga River Bridge

The Waihenga River Bridge is located on SH53 (route position 0/14.755) between Featherston and Martinborough (see figure 3.3). The bridge is situated approximately 575m to the east of the Jenkins Dip Floodway bypass. The eastbound bridge approach is characterised by a long, straight section approximately 580m in length prior to a right-hand horizontal curve leading up the bridge abutment, as can be seen in figure 3.4. The bridge is narrow and is regularly used by oversized farming vehicles. The approach operates with a 100km/h posted speed limit and requires a reduction in speed to drive over the bridge safely. The eastbound approach has an estimated two-way AADT of approximately 2500 vehicles (NZTA count site ID:05300016), 6.5% of which comprises HCV traffic.

A search of the NZTA crash database showed one minor injury crash at the bridge over the five-year period between 2004 and 2008. The crash involved an oversized farm vehicle, which was too wide to allow eastbound traffic to pass, travelling westbound across the bridge. As a result, an eastbound stationary vehicle that was waiting for the farm vehicle to clear was rear ended by another car unaware of the stationary vehicle.

At the time of investigation, speed advisory signs are located along the trial site approach. A 65km/h PW-17/PW-25 combination (15°–90° with curve advisory speed) is set approximately 230m from the start of the horizontal curve. In addition, because of the presence of the narrow bridge, a PW-44.1 sign combination (a 'caution wide vehicles' supplementary sign with a 'narrow bridge' sign) is located 145m prior to the start of the horizontal curve leading up to the bridge deck. The horizontal curve itself has a 65km/h PW-66 sign (a chevron board). A small number of rural properties have either driveway or paddock accesses onto both sides of the trial site. However, these were not expected to significantly affect through speeds during the trial.

Additional images of the trial site have been included within appendix B. They provide an overview of the bridge approach, and document the trial site before and after the road markings were implemented.

Figure 3.3 Location of bridge approach (image courtesy of Google Earth Pro Licence)

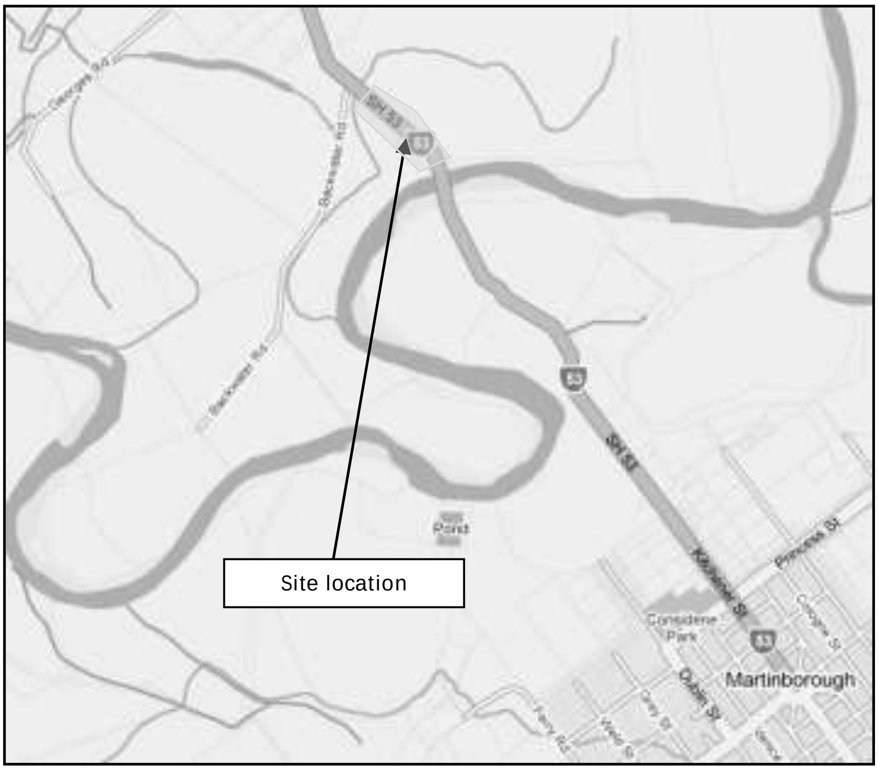
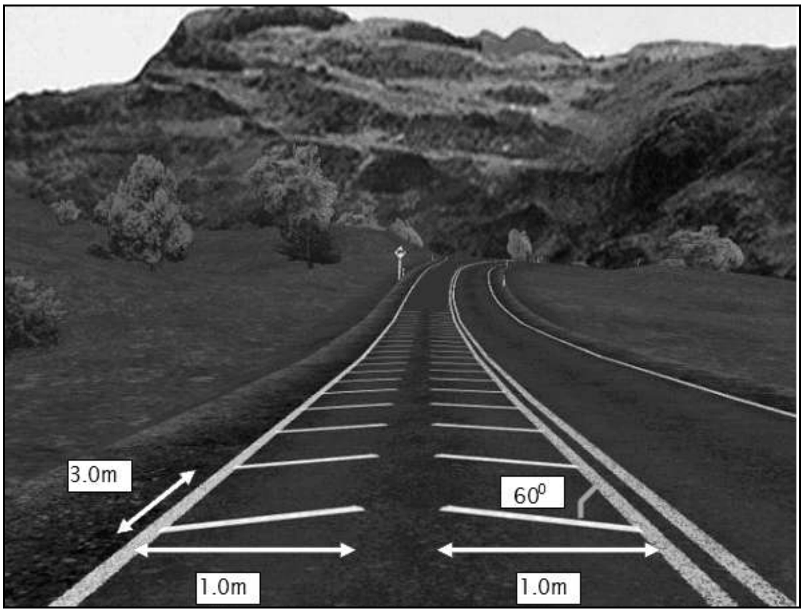


Figure 3.4 The straight section prior to the bridge approach (image from SH53 network video)

3.3 Line arrangement

The transverse lines used were 100mm wide and extended 1.0m into the traffic lane at a 60° angle, from the edgeline and centreline, as can be seen in figure 3.5. This is similar to the layout used by Charlton (2003), with a slight exception in that the length of the protruding lines is 0.5m shorter. For standard lane widths of 3.0m, this allows a gap of 1m between the edges of the transverse lines. The width within the middle of the traffic lane is thus sufficient to ease motorcyclist concerns surrounding loss of traction when travelling over the paint.

Figure 3.5 Visual concept of adopted layout (image modified from Charlton 2003)



3.4 Line spacing

The adopted spacing arrangement is represented visually in figure 3.5 above. The arrangement is evenly spaced at 3m intervals of separation as per the simulator trials undertaken by Charlton (2003). This would achieve an overall level of consistency with the simulator results. The lines begin approximately 410m from the hazard and then finish 110m from the hazard. Ending the treatment 110m from the hazard is consistent with Land Transport NZ (2005) whereby the lines are 'placed as to allow adequate time for the intended response from road users.' The arrangement gives approximately 300m of treatment length prior to the hazard. Note that the markings are not extended through the hazard area.

3.5 Line colour

Existing standards for rural roads in New Zealand such as *Guidelines for rural line marking & delineation RTS5* (Land Transport Safety Authority 1992) and MOTSAM specify that road markings such as those being attempted in this trial should be white. Therefore, white reflectorised markings were used in accordance with NZTA (formerly TNZ) specifications M/20 (TNZ 2000a), P/12 (TNZ 2000b) and M07 (NZTA 2009).

3.6 Evaluation

3.6.1 Experimental design

A before-and-after evaluation was developed to assess the free-flow vehicle operating speeds prior to and following installation of the transverse road markings. Assessing the mean and 85th percentile speeds would provide the most benefit for the purposes of this analysis. In addition to assessing the change in speed at each trial site, the following independent variables were also reviewed:

- whether the effectiveness of the markings were more influential during the weekday or weekend at each trial site
- whether the effectiveness of the markings was more influential on different vehicle classes at each trial site.

Using the equipment described in section 3.6.2, vehicle speed and axle data was collected continuously for seven days (a total of 168 consecutive hours), two weeks prior to, two weeks after and six months after the treatment was installed at each site. The data acquired during this time formed the basis of the assessment.

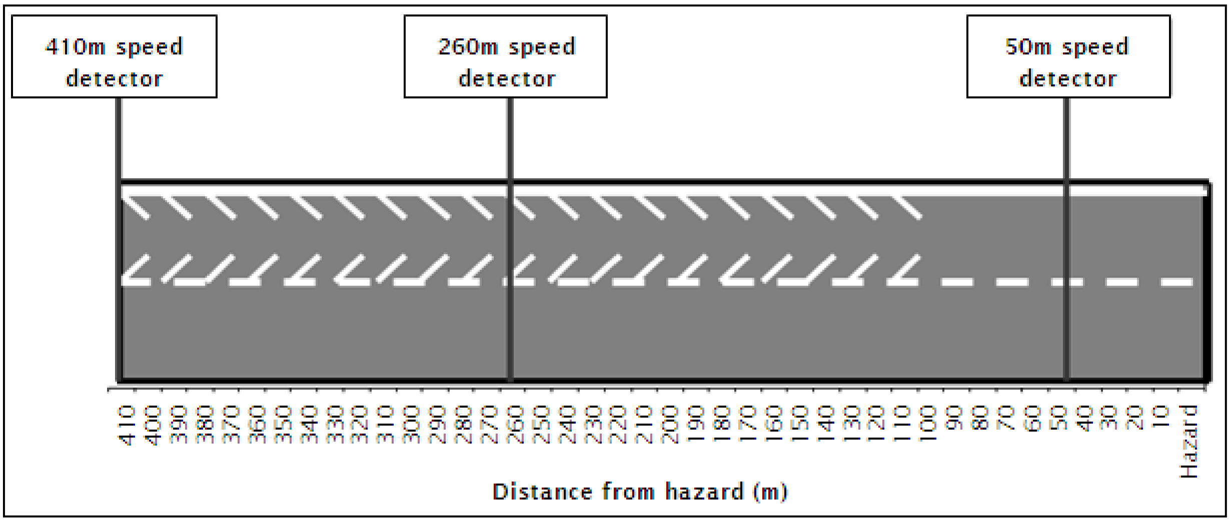
Note that all vehicle speeds recorded on a Friday were removed from consideration prior to the completion of the analysis. Friday contains a mixture of both commuter and weekend traffic. In this way, a comparison between weekday (Monday to Thursday) and weekend (Saturday and Sunday) vehicle speeds would be more accurate in distinguishing between the different factors potentially influencing speed change.

3.6.2 Equipment

The speed measurement apparatus consisted of three MetroCount® roadside units and their speed tube components per trial site. The MetroCount® roadside units allow the recording of both vehicle speed and axle information using the air pressure associated with a vehicle hit.

At each trial site, the three sets of speed measurement equipment were installed at approximately 50m, 260m and 410m from the hazard. This allowed vehicle speeds to be recorded at the start of the road marking treatment, the midpoint of the treatment and 50m prior to the hazard, as can be seen in figure 3.6.

Figure 3.6 Speed measurement locations within treatment length



To ensure that the apparatus was placed in exactly the same location during the before-and-after speed measurement analysis, note was made of the nail hole locations in the road seal resulting from the installation of the speed tubes. The nail holes were spray-painted and maintained for this purpose, as can be seen in figure 3.7. During visits to the site, the location of the nail holes were re-marked to ensure that the long-term measurements were recorded at the same locations.

Figure 3.7 Example of typical speed tube set-up, including spray-painted nail holes

In using MetroCount® roadside units, vehicle speeds could be differentiated by vehicle class. MetroCount® road side units use the number and spacing of successive axles to classify vehicles into one of fourteen classes defined by the NZTA's vehicle classification scheme (TNZ 1999 (TNZ 2004b)). The TNZ 1999 scheme can aggregate vehicles into either 'light' or heavy' vehicle categories as defined below.

- 'Light vehicles' are defined as TNZ 1999 vehicles classes 1 & 2. This includes cars with a wheelbase of 3.2m or less, and vans, utilities and light trucks up to 3.5 tonnes in gross laden weight.
- 'Heavy vehicles' are defined as TNZ 1999 vehicle classes 3 to 13. This includes two-axle trucks without trailers that are over 3.5 tonnes in gross laden weight, rigid trucks with or without a trailer, and articulated vehicles with up to five or more axles in total.

These vehicle definitions are similar to those defined in the NZTA's *Economic evaluation manual* (EEM) (NZTA 2010b). An overview of the TNZ 1999 scheme and the EEM table is provided in appendix C. Using these classifications, the effects of the transverse markings on different vehicle classes could be assessed.

3.6.3 Data collection

Vehicle speed and axle information was counted per hit over each set of speed tubes. The speed data was then filtered by direction of travel and by using a four-second headway. The directional filter allowed vehicle speeds to be considered through the length of the transverse marking treatment only. The four-second headway singled out free-operating travel speeds rather than drivers whose speeds were affected by slower vehicles they were following.

The dates of the recorded measurement periods, marking installation and a summary of site weather conditions are shown in tables 3.1 and 3.2. The weather was recorded using MetService information for Levin and Masterton rather than using on-site observations. As shown in the tables, the weather was consistent at both trial sites during the before-and-after measurement activities. Note that the average temperatures are higher for the speed surveys collected six months after the installation because of the seasonal change between winter and summer.

Table 3.1 SH57 trial site speed measurements

Date	Period	Average temperature (°C)	Days of rain
17/07/2009–24/07/2009	Two weeks before installation	12.14	5 out of 7
06/08/2009	Installation	–	–
25/08/2009–01/09/2009	Two weeks after installation	15.57	5 out of 7
08/02/2010–15/02/2010	Six months after installation	23.29	5 out of 7

Table 3.2 SH53 trial site speed measurements

Date	Period	Average temperature (°C)	Days of rain
28/07/2009–05/08/2009	Two weeks before installation	14.13	2 out of 7
18/08/2009	Installation	–	–
02/09/2009–09/09/2009	Two weeks after installation	14.43	2 out of 7
23/02/2010–02/03/2010	Six months after installation	25.86	3 out of 7

3.6.4 Data analysis techniques

To determine if the data recorded was statistically significant, the experimental design was developed with the aim of using a full-factorial univariate analysis of variance (ANOVA) with Opus's licensed SPSS software package. As an analytical tool, ANOVA can determine the statistical significance of any speed change for a variety of different independent variables, including vehicle class. A 95% confidence interval has been used to justify if a speed change was statistically significant or not.

3.6.5 Methodology limitations

Over the trial period, a number of limitations in both the methodology and, in some instances, the trial sites were observed. These limitations are important to consider when reviewing the statistical assessment of the data collected during the speed measurement activities.

3.6.5.1 Trial locations

The trial locations have a number of different physical geometric and layout properties. For such reasons, comparing vehicle speeds between the two trial sites had the potential to show varied speed reduction properties after the lines were installed. For the same reason, the results from the trials had the potential to be different from the results seen in international research as detailed in section 2.5.4. For example, as can be seen in figure 3.8, the beginning of the SH53 marking treatment is in the trough of the Jenkins Dip Floodway bypass. The first 50–100m of the treatment are slightly elevated and may be more visually striking than the first 50–100m of the SH57 site, which is flat.

Figure 3.8 Jenkins Dip Floodway bypass on the marked section of the SH53 site.

3.6.5.2 Speed measurement apparatus

The speed tubes used in the trial were found to have a number of reliability issues. To be consistent across the three speed tube sets at each site, a failure in one tube would mean the results of the others would be invalid. Unless regular supervision was available, it was difficult to determine if a tube had failed or not until the dataset had been reviewed.

At the SH57 trial site, the tube set posted at the 410m location failed after only two days into the pre-installation analysis. This delayed the trial by a week and a half to allow for the tubes to be re-installed and the data re-collected across the site. Similarly, during the initial post-installation period, the tube set placed 50m from the intersection partially failed after six and a half days. In this instance, it was decided that sufficient data had been collected for analysis purposes. No problems were detected during the long-term speed measurement activities. At the SH53 trial site, no speed tubes failed during either the pre- or initial post-installation analysis periods. However, during the long-term speed assessment, the speed tubes placed 410m from the hazard failed repeatedly. Every time the site was visited, half of this tube set was found to have been removed from the road. Despite the continued re-installation of the equipment, only 28 hours' worth of data was eventually recorded at this location. The long-term results at the 410m location on SH53 must therefore be considered with caution.

3.6.5.3 Environmental factors

At the SH53 trial site, the Jenkins Dip Floodway bypass was closed twice because of surface flooding. While the flooding and road closure did not occur during either of the analysis periods, a small number of cones were placed by the network maintenance contractors during the start of the measurement activities both before and two weeks after installation. The cones were placed at the beginning of the site over a short distance between 420 and 390m from the bridge hazard, as can be seen in figure 3.9. In both instances, no advanced warning signs were placed prior to the cones. For this reason, it has been assumed that vehicle speeds will not have been inadvertently affected by the road cones at this location. Nevertheless, the presence of the cones should be taken into account.

Figure 3.9 Cones observed at the start of the SH53 trial site

3.6.5.4 Other factors

No feedback from the public was received by the researchers during the duration of the trials. The South Wairarapa District Council received general information requests as to what the lines were supposed to do and why they were installed. In general, however, it was thought that the narrowness of the 100mm transverse bars when travelling at speed made them not as visually striking as they could have been.

4. Analysis

4.1 Filtered datasets

Vehicle speed data collected by the MetroCount® roadside units during each assessment period was filtered and checked against the evaluation methodology described in section 3.6. The number of filtered traffic counts recorded per trial site is shown in table 4.1. For ‘time’ and ‘vehicle class’, the same definitions as documented in sections 3.6.1 and 3.6.2 have been applied.

Table 4.1 Filtered vehicle counts (AADT) for each analysis period

Trial site	Analysis period	Time	Vehicle class	Distance from hazard		
				410m	260m	50m
SH57	Two weeks before installation	Weekday	Light	5004	5027	4935
			Heavy	921	871	958
		Weekend	Light	3090	3088	3063
			Heavy	200	194	214
		Total counts		9215	9180	9170
	Two weeks after installation	Weekday	Light	5349	5337	3669
			Heavy	887	896	678
		Weekend	Light	3108	3104	2972
			Heavy	213	207	270
		Total counts		9557	9544	7589
	Six months after installation	Weekday	Light	5566	5464	5374
			Heavy	1017	1008	1045
		Weekend	Light	3548	3517	3474
			Heavy	248	234	263
		Total counts		10,379	10,223	10,156
SH53	Two weeks before installation	Weekday	Light	3954	3972	3893
			Heavy	436	421	423
		Weekend	Light	1631	1635	1621
			Heavy	50	47	48
		Total counts		6071	6075	5985
	Two weeks after installation	Weekday	Light	3647	3594	3550
			Heavy	375	418	431
		Weekend	Light	1784	1774	1760
			Heavy	55	58	63
		Total counts		5861	5844	5804
	Six months after installation	Weekday	Light	1071	3852	3922
			Heavy	116	552	434
		Weekend	Light	0	2028	2026
			Heavy	0	89	63
		Total counts		1187	6521	6445

As discussed in section 3.6.5, only six and a half days of speed data were recorded across the 50m detector on SH57 in the short-term analysis period. In addition, long-term speed measurements at SH53's 410m detector were limited by the repeated failure of the speed tubes. At this 410m location, only 28 hours of data were able to be recorded. In both instances, the available data was still used to assess the relative speed change.

It is also acknowledged that some minor discrepancies can be seen between the numbers of recorded counts across each trial site detector during the same assessment period. It is possible that this could be a result of several possible factors:

- An error may have occurred during a single vehicle hit. In such instances, an individual vehicle may not have been picked up by the speed tubes.
- Vehicles accessing properties located along the length of each trial site may not have crossed all the tube sets.
- Vehicle bunching may have occurred over the length of the trial site. For instance, across the 410m detector, a set of vehicles following each other may have been over the four-second headway threshold. However, by the time the 50m detector was reached, the vehicles could have been spaced at a distance below this threshold.

Before undertaking a statistical assessment of the recorded before-and-after vehicle speeds, the normality of each trial dataset was first reviewed. A plot showing the frequency of all filtered vehicle speeds per measuring detector (rounded to a unit of 1km/h) is included in appendix D. From the plots, it can be seen that the speed data fits a normal distribution. While, in general, the data is slightly skewed with all but one being favoured towards the lower tail, ANOVA is a robust enough statistical method to determine the significance of the change in mean speed, given that the sample group sizes are similar.

4.2 ANOVA assessment

Because of the site-specific characteristics of the two trial sites, each site was assessed independently using ANOVA in the SPSS software package. A summary of the ANOVA results for SH57 and SH53 can be seen in tables 4.2 and 4.3, respectively. The ANOVA results generally show that at both trial sites and at almost all measurement locations, 'Period' (two weeks before, two weeks after and six months after installation) is a significant factor affecting the change in vehicle speed. Of particular interest to this study was that through ANOVA, the existence of interactive properties between the analysis period and the time (weekday v weekend) and vehicle class factors was determined. A detailed description of the results is provided in chapter 5.

Table 4.2 ANOVA results for the SH57 trial site

Dependent variable	Source	Type III sum of squares	df[a]	F[b]	Sig.[c]
50m mean speed	Corrected model	516,230	11	476.7	0.000
	Intercept	25,770,000	1	261,731.1	0.000
	Period	28,332	2	143.9	0.000
	Time	76	1	0.8	0.381
	Vehicle class	290,372	1	2949.3	0.000
	Period * time	1441	2	7.3	0.001
	Period * vehicle class	4718	2	24.0	0.000
	Time * vehicle class	3135	1	31.8	0.000
	Period * time * vehicle class	1711	2	8.7	0.000
	Error	2,648,749	26,903		
	Total	99,690,000	26,915		
	Corrected total	3,164,979	26,914		
260m mean speed	Corrected model	423,717	11	377.9	0.000
	Intercept	47,830,000	1	469,177.2	0.000
	Period	11,029	2	54.1	0.000
	Time	2	1	0.0	0.903
	Vehicle class	230,897	1	2265.0	0.000
	Period * time	679	2	3.3	0.036
	Period * vehicle class	55	2	0.3	0.763
	Time * vehicle class	366	1	3.6	0.058
	Period * time * vehicle class	451	2	2.2	0.110
	Error	2,949,731	28,935		
	Total	206,000,000	28,947		
	Corrected total	3,373,448	28,946		
410m mean speed	Corrected model	220,630	11	185.1	0.000
	Intercept	62,350,000	1	575,276.9	0.000
	Period	21,293	2	98.2	0.000
	Time	11	1	0.1	0.752
	Vehicle class	96,434	1	889.8	0.000
	Period * time	850	2	3.9	0.020
	Period * vehicle class	291	2	1.3	0.262
	Time * vehicle class	177	1	1.6	0.201
	Period * time * vehicle class	35	2	0.2	0.849
	Error	3,158,018	29,139		
	Total	249,600,000	29,151		
	Corrected total	3,378,648	29,150		

Notes to table 4.2:

a df = degrees of freedom

b F = the calculated F distribution value

c Sig. = significance of the F-test.

Table 4.3 ANOVA results for the SH53 trial site

Dependent variable	Source	Type III sum of squares	df[a]	F[b]	Sig.[c]
50m mean speed	Corrected model	280,840	11	250.4	0.000
	Intercept	13,240,000	1	131,575.5	0.000
	Period	34,514	2	169.2	0.000
	Time	25	1	0.2	0.621
	Vehicle class	40,720	1	399.3	0.000
	Period * time	409	2	2.0	0.134
	Period * vehicle class	1641	2	8.0	0.000
	Time * vehicle class	169	1	1.7	0.198
	Period * time * vehicle class	657	2	3.2	0.040
	Error	1,858,041	18,222		
	Total	117,000,000	18,234		
	Corrected total	2,138,881	18,233		
260m mean speed	Corrected model	101,626	11	50.2	0.000
	Intercept	16,860,000	1	91,634.9	0.000
	Period	615	2	1.7	0.188
	Time	1219	1	6.6	0.010
	Vehicle class	32,567	1	177.0	0.000
	Period * time	904	2	2.5	0.086
	Period * vehicle class	66	2	0.2	0.836
	Time * vehicle class	339	1	1.8	0.174
	Period * time * vehicle class	121	2	0.3	0.720
	Error	3,389,977	18,428		
	Total	139,300,000	18,440		
	Corrected total	3,491,603	18,439		
410m mean speed	Corrected model	206,398	9	124.8	0.000
	Intercept	8,736,374	1	47,552.9	0.000
	Period	47,377	2	128.9	0.000
	Time	39	1	0.2	0.645
	Vehicle class	34,428	1	187.4	0.000
	Period * time	12	1	0.1	0.796
	Period * vehicle class	789	2	2.1	0.117
	Time * vehicle class	212	1	1.2	0.283
	Period * time * vehicle class	127	1	0.7	0.406
	Error	2,408,372	13,109		
	Total	95,100,000	13,119		
	Corrected total	2,614,771	13,118		

Notes to table 4.3:

a df = degrees of freedom

b F = the calculated F distribution value

c Sig. = significance of the F-test.

5. Field trial results

5.1 General before-and-after speed changes

The overall speed changes occurring between the periods before and after installation of the markings are summarised in tables 5.1 and 5.2 for the SH57 and SH53 trial sites, respectively. This information is represented visually in figures 5.1and 5.2. Note that for this comparison, the mean speeds estimated by ANOVA have been displayed. In general, the mean speeds typically decreased as vehicles approached the intersection or bridge hazard, regardless of the assessment period or if the marking treatment was installed. The impact of the transverse lines on driver behaviour is determined through the comparison of the change in mean speed at each speed detector between the pre-installation, short and long-term assessment periods.

Table 5.1 Overall speed results for the SH57 trial site

Period	Statistic (in km/h)	Distance from SH57 intersection hazard		
		410m	260m	50m
Before installation	Mean speed	91.0	80.6	56.0
	85th percentile	103.3	95.0	69.4
2 weeks after	Mean speed	89.7	80.0	57.6
	85th percentile	102.2	94.7	69.9
Short-term speed change	Marginal mean speed	-1.3*	-0.6	1.6*
	85th percentile	-0.8*	-0.3	0.5*
6 months after	Mean speed	87.1	77.8	53.2
	85th percentile	100.0	92.5	67.1
Long-term speed change	Marginal mean speed	-3.9*	-2.7*	-2.8*
	85th percentile	-3.3*	-2.5*	-2.3*

* Speed change is significant at the 0.05 level

Table 5.2 Overall speed results for the SH53 trial site

Period	Statistic (in km/h)	Distance from SH53 bridge hazard		
		410m	260m	50m
Before installation	Mean speed	82.3	82.3	78.8
	85th percentile	97.4	96.5	90.8
2 weeks after	Mean speed	79.7	83.1	78.6
	85th percentile	94.5	97.2	91.6
Short-term speed change	Marginal mean speed	-2.6*	0.9	-0.2
	85th percentile	-2.9*	0.7	0.8
6 months after	Mean speed	70.1	83.5	70.7
	85th percentile	94.2	99.7	84.6
Long-term speed change	Marginal mean speed	-12.2*	1.2	-8.1*
	85th percentile	-3.2*	3.2	-6.2*

* Speed change is significant at the 0.05 level

Figure 5.1 ANOVA-adjusted mean speeds (bars) and observed 85th percentile speeds (horizontal lines) before and after installation of transverse road markings at the SH57 trial site

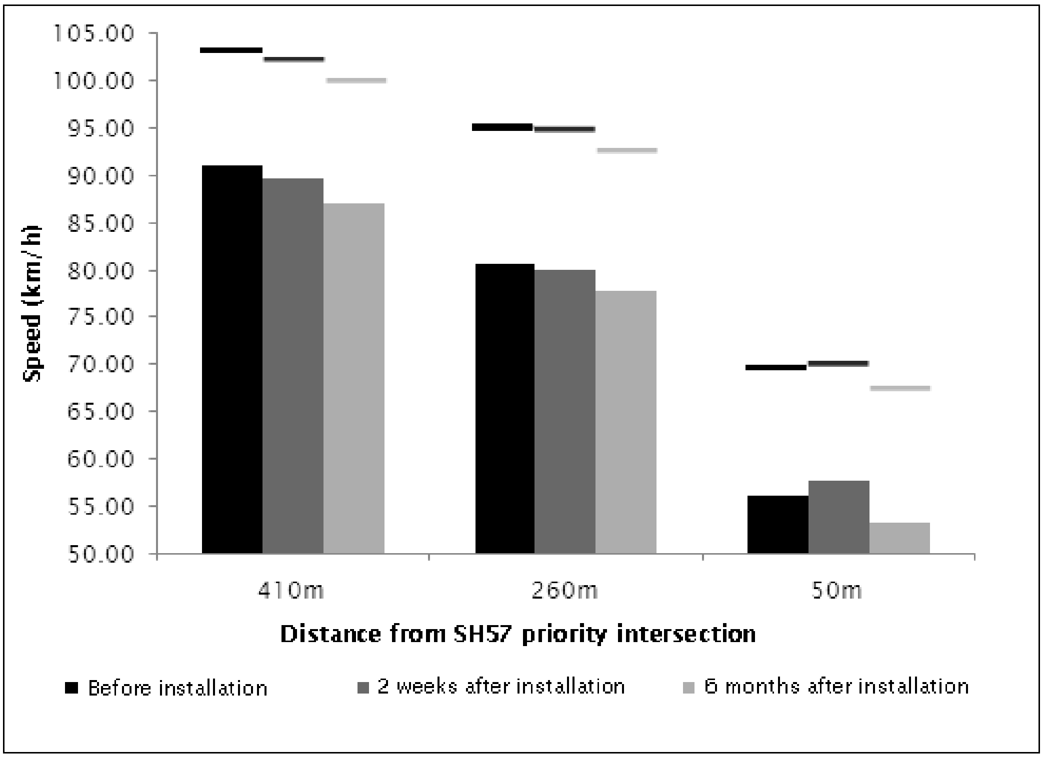
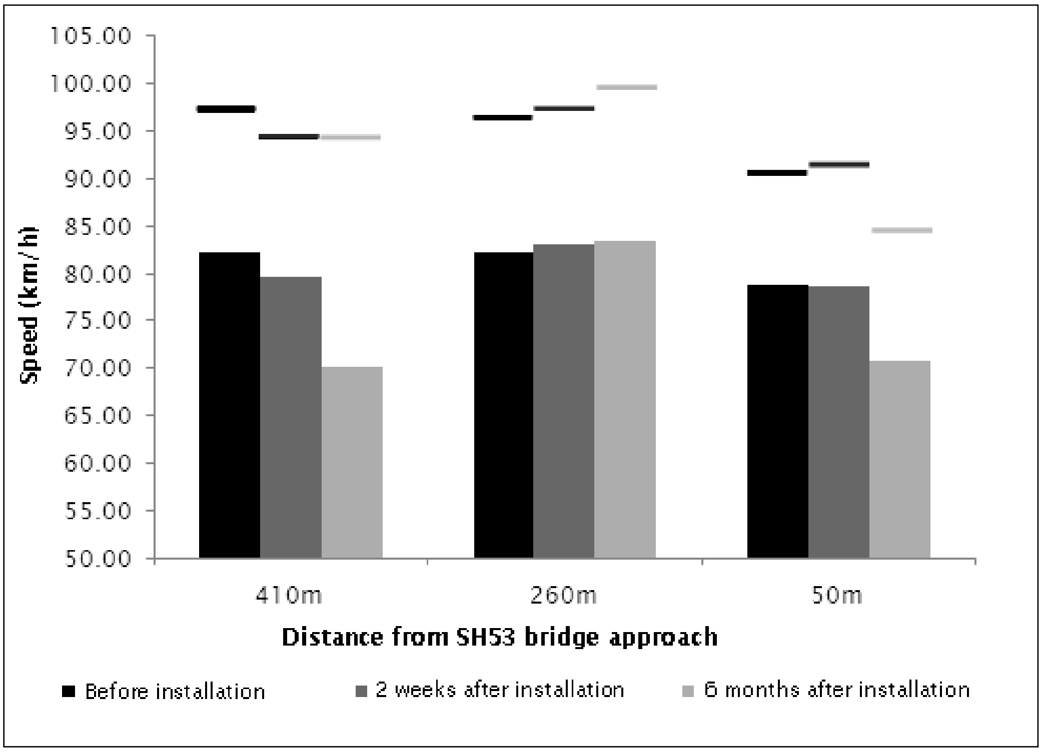


Figure 5.2 ANOVA adjusted mean speeds (bars) and observed 85th percentile speeds (horizontal lines) before and after installation of transverse road markings at the SH53 trial site



As can be seen from the tabular and graphical outputs, the main short-term effect of the transverse marking arrangement at SH57 was to reduce mean speeds by approximately 1.3km/h at the start of the treatment (410m from the intersection). At 260m from the hazard, this speed reduction effect was found to wear off, with vehicle speeds being only slightly lower than they were prior to installation of the markings. At 50m from the hazard, mean vehicle speeds were slightly higher than those obtained prior to the installation of the lines. In the long term, mean speeds 410m from the intersection were found to be 3.9km/h less than the speeds recorded prior to the installation of the lines. However, in contrast to the short-term results, this statistically significant reduction was found to lessen only slightly through the remainder of the intersection approach. Statistically significant long-term reductions of 2.7km/h and 2.8km/h were recorded at the 260m and 50m positions prior to the intersection, respectively.

At SH53, the main short-term effect of the transverse marking arrangement was to reduce mean speeds by 2.6km/h at the start of the treatment (410m from the bridge). At 260m from the hazard, the speed reduction effect was found to wear off, with speeds being approximately 1.0km/h higher than before the lines were installed. At 50m from the hazard, the mean speeds were slightly higher than those obtained prior to the installation of the lines. Six months after the lines were installed at SH53, vehicle speeds appear to have greatly reduced at the start of the treatment length. It was found that at 410m from the bridge hazard, the mean speed was 12.2km/h less than the values recorded prior to the installation of the lines. However, as can be seen in table 4.1, long-term recorded data is distinctly lacking at this detector. Therefore, the results at this location should be taken with caution. As with the initial results, the speed reduction appears to be marginal within the next 150m. At 260m from the bridge, the mean speeds are slightly higher than they were before the markings were implemented; however, this change is statistically non-significant. At 50m from the bridge hazard, the long-term vehicle speeds were found to have decreased substantially and a statistically significant reduction in mean speed of 8.1km/h was determined at this location.

In general, at both trial sites, regardless of the short- or long-term assessment period, the main effect of the transverse marking arrangement is to reduce vehicle speeds upon entering the treatment. The speed reduction effect then typically wears off 150m into the treatment, with vehicle speeds being at similar levels to those seen prior to the installation of the markings. Vehicle speeds 50m from the hazard in the long term were generally found to be lower than they were before the lines were implemented.

5.2 Weekday vs weekend before-and-after speed changes

A key desire of the trials was to determine whether the effectiveness of the transverse lines was more influential on driver behaviour during the weekday or the weekend. It was initially hypothesised that by considering this factor, it may be possible to determine if any distinction can be made between the markings' effect on daily commuter traffic and on occasional drivers. From the ANOVA assessment, it was found that at some tube locations within each trial site, statistically significant interactions appeared between the analysis period and the weekday vs weekend factor. Tables 5.3 and 5.4 show the marginal mean speeds recorded for each measurement period, broken down by time (weekday vs weekend). Visual representations of the mean and observed 85th percentile speeds are shown in figures 5.3 and 5.4.

Table 5.3 Speed results by weekday and weekend for the SH57 trial site

Period	Statistic (in km/h)	Distance from SH57 intersection hazard		
		410m†	260m	50m
Before installation	Mean speed	90.6 [91.5]	80.2 [81.0]	55.8 [56.2]
	85th percentile	103.1 [103.5]	94.8 [95.3]	69.7 [69.0]
2 weeks after installation	Mean speed	89.8 [89.7]	80.0 [80.0]	57.0 [58.1]
	85th percentile	102.2 [102.3]	94.9 [94.2]	70.6 [69.2]
Short-term speed change	Mean speed	-0.8* [-1.8*]	-0.2 [-1.0]	1.2* [1.9*]
	Speed difference	-1.0	-0.8	0.7
	85th percentile	-0.9* [-1.2*]	0.1 [-1.1]	0.9* [0.2*]
6 months after installation	Mean speed	87.5 [86.8]	78.2 [77.5]	53.7 [52.8]
	85th percentile	100.6 [97.91]	92.8 [91.5]	67.6 [66.3]
Long-term speed change	Mean speed	-3.1* [-4.7*]	-2.0* [-3.5*]	-2.1* [-3.4*]
	Speed difference	-1.6#	-1.5	-1.3
	85th percentile	-2.5* [-5.6*]	-2.0* [-3.8*]	-2.1* [-2.7*]

† Weekend speeds are shown in square brackets.

* indicates that an individual weekday or weekend speed change is statistically significant at the 95% confidence level

# indicates that the difference between the weekday and weekend mean speed changes (interaction) is significant at the 95% confidence level

Table 5.4 Speed results by weekday and weekend for the SH53 trial site

Period	Statistic (km/h)	Distance from SH53 bridge hazard		
		410m†	260m	50m
Before installation	Mean peed	82.4 [82.3]	81.9 [82.6]	78.3 [79.2]
	85th percentile	97.5 [97.1]	96.6 [96.2]	90.7 [90.9]
2 weeks after installation	Mean speed	80.0 [79.5]	82.9 [83.4]	79.2 [78.0]
	85th percentile	94.0 [95.2]	96.7 [98.1]	91.6 [91.6]
Short-term speed change	Mean speed	-2.4* [-2.8*]	1.0 [0.8]	0.9* [-1.2]
	Speed difference	-0.4	0.2	2.1
	85th percentile	-3.5* [-1.9*]	0.1 [1.9]	0.9* [0.7]
6 months after installation	Mean speed	70.1 [N/A]	82.0 [85.0]	70.9 [70.5]
	85th percentile	94.2 [N/A]	99.5 [100.0]	84.3 [84.9]
Long-term speed change	Mean speed	-12.3* [N/A]	0.1 [2.4]	-7.4* [-8.7*]
	Speed difference	N/A	2.3	-1.3
	85th percentile	-3.3* [N/A]	2.9 [3.8]	-6.4* [-6.7*]

† Weekend speeds are shown in square brackets.

* indicates that an individual weekday or weekend speed change is statistically significant at the 95% confidence level

# indicates that the difference between the weekday and weekend mean speed changes (interaction) is significant at the 95% confidence level

N/A indicates that no vehicle speed data was available for this factor.

Figure 5.3 Mean weekday and weekend speeds (columns) and 85th percentile speeds (horizontal lines) before and after installation of transverse road markings at Arapaepae Road southbound approach)

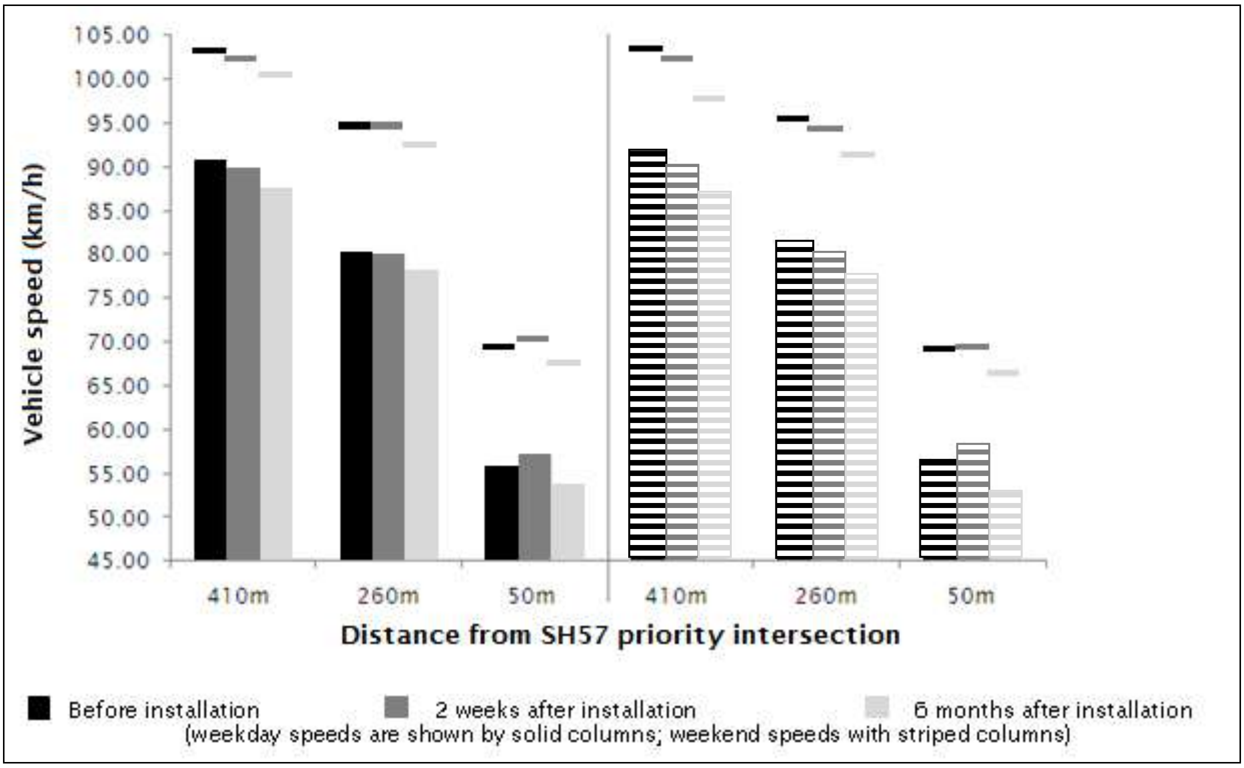
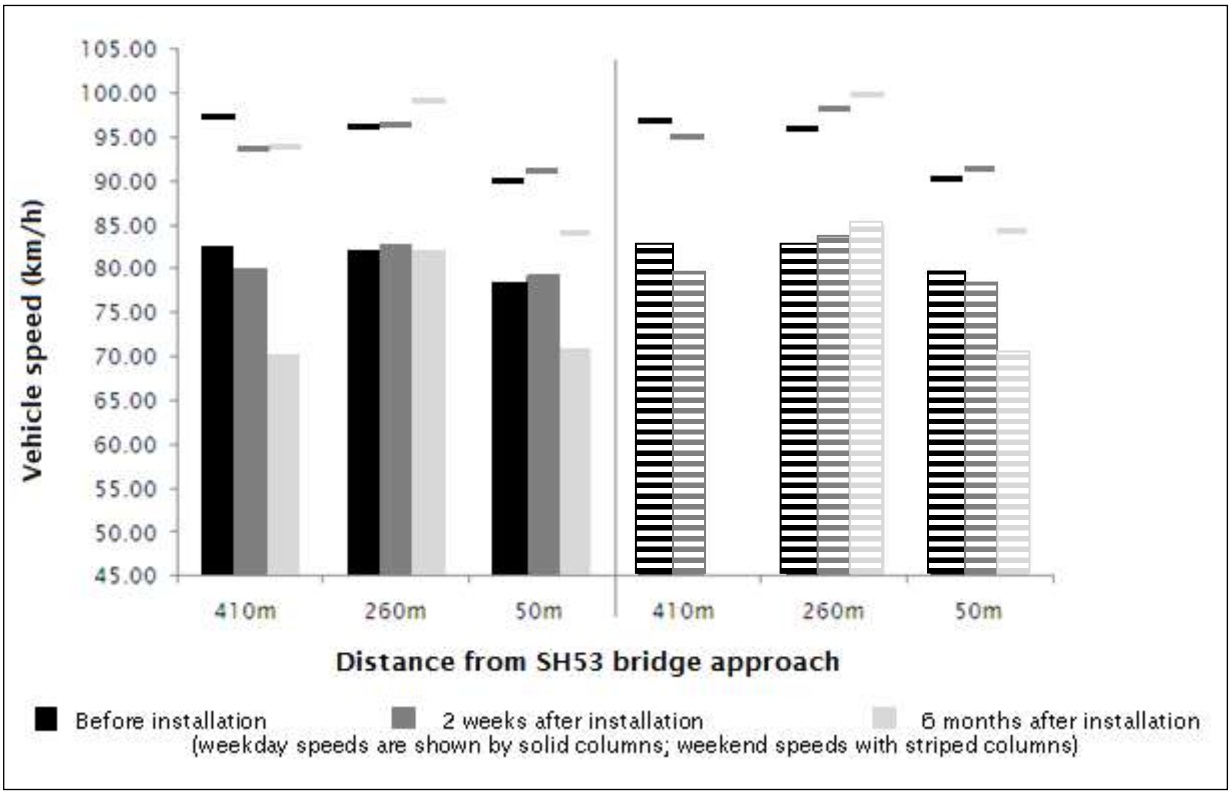


Figure 5.4 Mean weekday and weekend speeds (columns) and 85th percentile speeds (horizontal lines) before and after installation of transverse road markings at Waihenga Bridge eastbound approach (SH53)



Note: data was not available for weekends six months after installation at the 410m point

Regardless of the trial site, no interactive properties were found between the weekday/weekend factor and the short-term analysis period. That is, any difference between the changes in mean short-term weekday and weekend vehicle speed was possibly a result of chance. The results have thus indicated that in the short term, the marking arrangement has had the same effect on drivers (commuter or occasional) travelling over the treatment during either the weekday or weekend.

The weekday/weekend factor did, however, show interactive properties in the long-term analysis period. At the SH57 410m detector, the long-term mean speeds were found to be 3.1km/h and 4.7km/h lower than the speeds recorded prior to the installation of the markings during the weekday and weekend respectively. Because of the statistical significance of the interaction between the weekday/weekend and period factors, it can be said that at this location, the marking arrangement had a greater effect on long-term vehicle speeds during the weekend. As insufficient data was recorded from the long-term SH53 410m detector, the same trend could not be concluded at the SH53 trial site. Over the remainder of the trial length at both sites, no interaction between the changes in weekday and weekend mean vehicle speeds was determined in the long term. Any difference observed between the long-term weekday and weekend results at these locations is possibly a result of chance.

5.3 Vehicle type before and after speed changes

The final component of the trials was to determine whether the effectiveness of the transverse lines was more influential on drivers of different vehicle classes. In this way, it could be determined whether the marking arrangement has the potential to address vehicle-specific road safety issues.

From the ANOVA assessment, it was shown that at some locations within each treatment, statistically significant interactions could be seen between the analysis period and vehicle class. Tables 5.5 and 5.6 show the marginal mean speeds recorded for each measurement period broken down by vehicle class.

Table 5.5 Speed results by light and heavy vehicle type for the SH57 trial site

Period	Statistic (in km/h)	Distance from SH57 intersection hazard		
		410m†	260m	50m
Before installation	Mean speed	94.3 [87.7]	86.2 [75.0]	62.2 [49.7]
	85th percentile	103.7 [95.5]	95.6 [84.0]	70.2 [58.3]
2 weeks after	Mean speed	93.2 [86.2]	85.4 [74.6]	62.4 [52.7]
	85th percentile	102.7 [94.7]	95.3 [83.8]	70.6 [60.7]
Short-term speed change	Mean speed	-1.1* [-1.5*]	-0.8* [-0.4]	0.2 [3.0*]
	Speed difference	-0.4	-0.4	2.8#
	85th percentile	-1.0* [-0.8*]	-0.3* [-0.2]	0.4 [2.4*]
6 months after	Mean speed	90.9 [83.4]	83.4 [72.3]	59.8 [46.6]
	85th percentile	100.7 [91.6]	93.2 [81.7]	67.9 [54.2]
Long-term speed change	Mean speed	-3.4* [-4.4*]	-2.8* [-2.7*]	-2.4* [-3.1*]
	Speed difference	-1.0	-0.1	-0.7
	85th percentile	-3.4* [-3.9*]	-2.4* [-2.3*]	-2.3* [-4.1*]

† HCV speeds are shown in square brackets

* indicates that an individual light or heavy speed change is statistically significant at the 95% confidence level

# indicates that the difference between the light and heavy mean speed changes (interaction) is significant at the 95% confidence level.

Table 5.6 Speed results by light and heavy vehicle type for the SH53 trial site

Period	Statistic (in km/h)	Distance from SH53 bridge hazard		
		410m†	260m	50m
Before installation	Mean speed	86.7 [78.0]	86.1 [78.4]	82.1 [75.5]
	85th percentile	97.8 [90.8]	96.9 [89.6]	91.1 [84.4]
2 weeks after	Mean speed	84.5 [75.0]	86.6 [79.7]	82.6 [74.6]
	85th percentile	94.8 [86.5]	97.7 [90.5]	92.1 [86.1]
Short-term speed change	Mean speed	-2.2* [-3.0*]	0.5* [1.2]	0.5* [-0.9]
	Speed difference	-0.8	0.7	1.4
	85th percentile	-3.2* [-4.8*]	0.4* [1.4]	0.8* [1.4]
6 months after	Mean speed	75.7 [64.5]	87.2 [79.8]	76.0 [65.4]
	85th percentile	94.9 [85.3]	100.1 [95.4]	85.0 [75.7]
Long-term speed change	Mean speed	-11.0* [-13.4*]	1.1* [1.3]	-6.0* [-10.1*]
	Speed difference	-2.4	0.2	-4.1#
	85th percentile	-2.9* [-5.5*]	3.2* [5.8]	-6.1* [-8.7*]

† HCV speeds are shown in square brackets

* indicates that an individual light or heavy speed change is statistically significant at the 95% confidence level

# indicates that the difference between the light and heavy mean speed changes (interaction) is significant at the 95% confidence level.

A visual representation of the light and heavy vehicle mean and observed 85th percentile speeds can be seen in figures 5.5 and 5.6.

Figure 5.5 Mean light and heavy vehicle speeds (columns) and 85th percentile speeds (horizontal lines) before and after installation of transverse road markings at Arapaepae Road southbound approach (SH57)

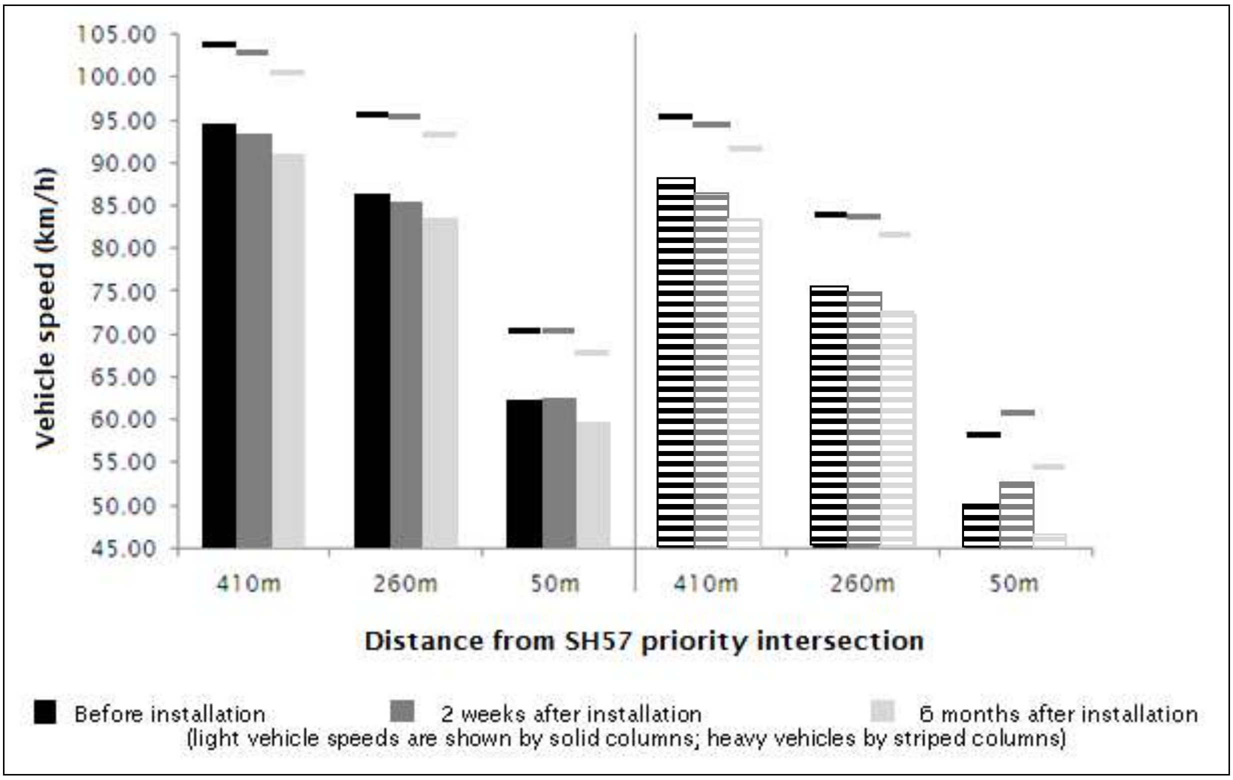
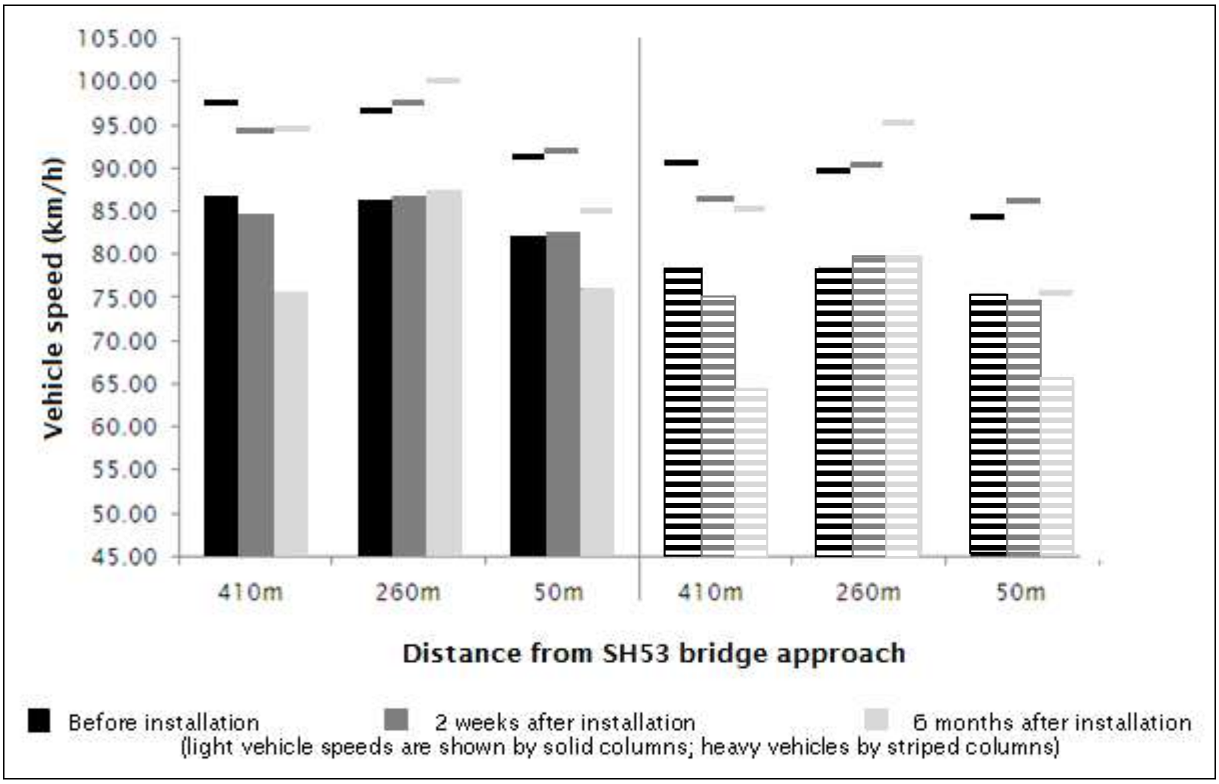


Figure 5.6 Mean light and heavy vehicle speeds (columns) and 85th percentile speeds (horizontal lines) before and after installation of transverse road markings at Waihenga River Bridge eastbound approach (SH53)



As can be seen in the tabular outputs, 50m prior to the SH57 intersection, mean HCV speeds were, in the short term, found to be 3.0km/h higher than those recorded prior to the installation of the lines. Conversely, light vehicle speeds did not alter significantly in the short term. Owing to the statistical significance of the interaction, the change in mean short-term HCV speed was greater than that of light vehicles at this location. For the remainder of the detectors at both trial sites, no interaction was found between the vehicle class and the short-term period factors. At these remaining detectors, any difference between the short-term mean speed changes for light and heavy vehicles was possibly a result of chance. Therefore, the transverse line marking arrangement has had the same effect on drivers of different vehicle types at the remaining speed detectors in the short term.

In the long term, interactive properties between vehicle class and the analysis period were found only at the SH53 detector 50m from the bridge approach. At this location, the long-term mean speeds were found to be 6.0km/h and 10.1km/h less than those recorded prior to the implementation of the markings for light and heavy vehicles, respectively. Because of the statistical significance of the interaction, at this location, HCVs were affected more than light vehicles by the markings in the long term. However, for the remainder of the detectors at both trial sites, no long-term interactive properties were found. Any differences between the light and heavy vehicle long-term speeds were by chance. Therefore, at the remaining detectors, the transverse line marking arrangement has had the same effect on drivers of different vehicle classes in the long term.

6. Discussion

The primary objective of the two trials was to assess the speed of vehicles travelling towards a hazardous location in a before-and-after (baseline and post-intervention) evaluation. The analysis compares the mean and 85th percentile speeds measured two weeks before, two weeks after and six months after the chosen transverse marking arrangement was installed at each trial site. The trial sites were located on the southbound approach to the Arapaepae Road intersection (SH57) and on the eastbound approach to the Waihenga River bridge (SH53). Vehicle speed measurements were recorded at three locations within each trial site. These measurement locations were consistent with the start of the markings (410m from the hazard), the midpoint of the markings (260m from the hazard) and at 50m prior to the site-specific hazard. ANOVA was used to determine the statistical significance of the changes in mean speed and to assess the different factors possibly influencing driver behaviour.

It was found that mean and 85th percentile speeds typically decreased at both treatment sites as vehicles approached either the bridge or intersection hazard. This occurred regardless of whether the transverse lines were installed or not. However, at both trial sites, the main initial effect of the transverse marking arrangement was a reduction in mean speeds of 1–2.6km/h at the start of the treatment (410m from the hazard). At 260m from the hazard, the speed reduction effect appears to wear off and therefore speeds were similar to or slightly higher than before the lines were installed. At 50m from each hazard, the short-term mean speeds are either the same as or slightly higher than those obtained prior to the installation of the lines.

In contrast to the short-term assessment, the long-term results varied considerably. At the SH57 site, the mean vehicle speeds at the start of the treatment were found to be almost 4.0km/h lower than they were prior to the installation of the lines. Through the remainder of the SH57 treatment, this reduction was maintained, although at a lesser degree. Mean vehicle speed reductions of 2.7 and 2.8km/h were found at the 260m and 50m measurement locations, respectively. At the SH53 site, the long-term vehicle speeds were found to reduce dramatically at the treatment start and end. Mean speed reductions of 12.2km/h and 8.1km/h were determined at these locations, respectively. At the SH53 treatment's midpoint, long-term speeds were similar to pre-installation levels. Based on the long-term results, it can be said that the speed reduction properties of the lines have improved over time.

Regardless of the variation between the short- and long-term results, it has been consistently shown that the transverse markings reduce vehicle speeds at the start of each treatment (410m from the hazard). Therefore, one can assume that the transverse lines have an alerting property; that is, drivers have reacted to the markings as they are first observed and have entered into the marking treatment at a lower speed out of precaution. Excluding the long-term result at SH57, similar results have also been determined at the midpoint of both marking treatments. At this location, vehicle speeds in the short and long term were at levels similar to those recorded during the pre-installation period. It is likely that at this midpoint location, drivers have become accustomed to the presence of the lines over the first 150m of the treatment. Finally, at 50m from each hazard and based purely on the long-term speed data, it can be said that vehicles are arriving at lower speeds than they were prior to the installation of the lines. One possible explanation for this is that because of the heightened perception of risk induced upon entering each treatment, drivers have become more prepared to react to the visual cues associated with the upcoming intersection or bridge hazard.

The magnitude of the mean speed changes was found to vary between the SH53 and SH57 trial sites. It is likely that this is related to the physical geometry and layout of each individual site. The two sites are completely different for a number of reasons and one cannot expect drivers to exhibit exactly the same response. As described in section 3.6.5, the start of the SH53 marking treatment is in the trough of the Jenkins Dip Floodway bypass. The first 50–100m of the treatment are slightly elevated and may be more visually striking than the first 50–100m of the SH57 site, which is flat, as can be seen in figure 6.1. This may have contributed to the SH53 site having higher reduction values recorded at the beginning of the marking treatment.

Figure 6.1 SH57 trial site with level geometric profile

In addition to the overall speed changes observed at each trial site, a comparison between the weekday and weekend mean speeds was also conducted. In this way, it was hoped that one could identify if drivers going regularly over the lines (weekday commuters) were affected to a lesser extent than those doing it occasionally (weekend traffic). Through the use of ANOVA, the interactive properties between the weekday v weekend factor and each measurement period were assessed. No interactive properties were identified at either of the trial sites in the short term. Any differences between the changes in mean short-term weekday and weekend vehicle speeds were a result of chance. In the long term, interactive properties were only identified at the entry into the SH57 treatment (410m from the hazard). At this location, the change in long-term mean speeds was found to be 1.6km/h greater during the weekend than in the weekday. At the remaining measurement locations for both trial sites, no interactive properties were identified.

Based on the results of both trial sites and assessment periods, it can be said that, in general, the marking treatment has not conclusively demonstrated that the lines are more influential during either the weekday or weekend periods. The only reliable difference was observed at the start of the SH57 treatment (410m), where weekend road users displayed greater speed reductions than weekday users.

The final component of the trial was to determine if the transverse marking arrangement was more influential on drivers of different vehicle classes. In this way, it could be proven whether the marking arrangement could be used to address vehicle-specific excessive speed issues. Through the use of ANOVA, the interactive properties between the light v heavy vehicle factor and each measurement period were assessed. In the short term, interactive properties were found only at 50m from the intersection hazard on SH57. At this location, speeds of HCVs (but not light vehicles) were greater than they were prior to the installation of the markings; the changes in short-term HCV speeds were found to be statistically larger than those determined for light vehicles. No interactive properties were identified in the short term at the remainder of the measurement locations of both trial sites. It could be said that any differences found between the mean short-term light and heavy vehicle speed changes at the remaining locations were by chance.

In the long-term assessment period, interactive properties were only identified at the SH53 trial site 50m from the bridge hazard. At this location, the long-term mean speeds were found to be 6.0km/h and 10.1km/h less than the speeds recorded prior to the installation of the lines. Because of the statistical significance of the interaction at this location, HCVs were affected by the marking arrangement to a greater degree than light vehicles. At the remaining detectors of both trial sites, no further interactive properties were determined. Therefore, it could be said that at the remaining detectors, the markings have affected the two vehicle classes by the same degree. Any difference observed between the light or heavy vehicle speed change in the long term at these locations was a result of chance.

The results of both trial sites and assessment periods suggest that we have insufficient evidence to say with certainty that the marking treatments were more influential on drivers of one vehicle class over another. No common trends were identifiable between the trial sites and across the different measurement locations for this comparison. It has therefore been statistically determined that the marking treatment has affected drivers of both light and heavy vehicle drivers by the same degree.

7. Conclusions

The literature review and subsequent field trials have successfully demonstrated that transverse road markings have the potential to be used as a practical speed mitigation device on high-speed approaches to rural hazards in a New Zealand context. In both the international research and the field trials conducted as part of this report, statistically significant reductions in mean vehicle speeds were observed at various intervals within the treatment site. However, individual variations in the results seen between trial sites were not surprising. Both the SH57 and SH53 trial sites have a number of different physical characteristics, such as elevation, road quality and the type of hazard they are approaching. If the markings are to be deployed at other rural New Zealand high-speed environments, it is possible that the markings could again display varying speed reduction properties.

From the short- and long-term results, it was clearly demonstrated that the largest marking effect was at the start of the treatment. At this location, vehicles may have slowed down out of precaution upon entering the marking treatment. Because of the length of the adopted marking arrangement, drivers may have had sufficient time to exhibit a habitual response by the time they reached the treatment midpoint. That is, drivers generally returned to their pre-installation speeds at this location prior to receiving the visual cues associated with each trial hazard. Based on this finding, it may be of benefit to reduce both the length of the marking treatment, and the distance at which it begins and ends from the hazard. Continuing the markings to a point closer to the hazard would align the treatment design more closely with the UK's standardised yellow bar arrangement, which terminates 50m from the hazard. Adopting either of these approaches would probably result in the additional benefit of revealing a greater number of applicable sites. As described, locating trial sites with long, straight sections in excess of 400m prior to a hazard was immensely difficult. Specifically, by reducing the distance between the start of the markings and the hazard, this speed mitigation device could be more widely applied in a New Zealand context.

In addition, the speed reduction could perhaps have been enhanced by increasing the presence of the lines. The adopted methodology used 100 equally spaced sets of 100mm bars. Visually, this may not have been as pronounced as desired. It was found in literature that the bar widths were often as wide as 600mm. This line width is the same as that adopted by the UK's standardised yellow bar arrangement. This may explain why the field trials did not exhibit mean speed reductions as high as those found in some overseas literature.

Ultimately, however, the overall success or failure of the transverse road markings as an accident prevention measure should not be purely based on the changes in vehicular speed. Because of the limited time available for this trial, the hypothesis that a positive relationship potentially exists between reduced travel speed and a reduction in speed-related crashes has had to be assumed. The markings' effect on safety through a reduced accident history will be a more telling statistic to judge the outcomes of the trials by.

8. Recommendations

Based on the findings of the literature review and from the results of the two field trials, it can be said that transverse road markings do affect driver behaviour by producing lower vehicle speeds within a treatment. In this way, transverse markings have shown the potential to make a cost-effective attempt at reducing fatal and serious injury crashes as a consequence of speeding on a hazard approach. Therefore, it is recommended that further investigations and trials are conducted prior to the establishment of a standardised procedure. If these trials are undertaken, consideration should be given to the following methodology modifications:

- The distance between the between the hazard and the start/end point of the marking treatment should be reduced. A 150m marking treatment starting between 200–260m from the hazard should result in reduced vehicle approach speeds closer to the hazard.
- Increasing the width of the individual bars to at least 500mm will make the markings visually more pronounced. The distance between the bars should be increased from 3m to 10m to account for the increase in bar width.
- The long-term assessment period should be increased from 6 to 12 months after the marking arrangement is installed. In this way, a limited assessment of accident data can be made in addition to assessing the change in vehicle speed.
- A comparison between the day and night speed reduction properties should be investigated. To conduct this analysis, it is recommended more accurate light or UV levels are used as a basis for this assessment rather than the more easily attainable sunrise/sunset times from MetService.
- Ideally, an additional review of the crash history could occur five years after the installation of the markings. This would provide sufficient time to assess the true effects of the lines on accident performance.
- Increasing the number of high-speed rural trial sites from two to five or more would be of benefit. This will help account for any variation between the individual trial sites as was found in this study.

These recommendations should allow for sufficient empirical based evidence to formalise a standardised procedure for transverse road marking in a New Zealand context. In this way, the future implementation of this perceptual countermeasure could assist in the desired reduction of injury road crashes resulting from excess speeding on hazard approaches.

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Appendix A SH57 site images

Figure A1 Arapaepae Road (SH57), 410m from the intersection prior to transverse marking installation

Figure A2 Arapaepae Road (SH57), 410m from the intersection after installation of the transverse markings

Figure A3 Arapaepae Road (SH57), 260m from the intersection prior to transverse marking installation

Figure A4 Arapaepae Road (SH57), 260m from intersection after installation of the transverse markings

Figure A5 Arapaepae Road (SH57), 50m from the intersection

Note: This location looked the same before and after installation of the transverse markings.

Appendix B SH53 site images

Figure B1 Eastbound Waihenga Bridge approach (SH53), 410m from the horizontal curve prior to transverse marking installation

Figure B2 Eastbound Waihenga Bridge approach (SH53), 410m from the horizontal curve after installation of the transverse markings

Figure B3 Eastbound Waihenga Bridge approach (SH53), 260m from the horizontal curve prior to transverse marking installation

Figure B4 Eastbound Waihenga Bridge approach (SH53), 260m from the horizontal curve after installation of the transverse markings

Figure B5 Eastbound Waihenga Bridge approach (SH53), 50m from the horizontal curve

Note: the appearance of this location was the same before and after installation of the transverse markings.

Appendix C Vehicle classifications

C1 TNZ 1999 classification scheme

Table C1 TNZ Vehicle classification scheme (adapted from TNZ (2004b))

Feature	Class						
	1	2	3	4	5	6	7
Axles	2	3	2	3	3	4	4
Distinguishing feature or identification algorithm	No. of axles and wheelbase <3.2m	3 axles and sp. ax1 – ax2 <3.2m OR 4 axles and (sp. ax1 – ax2 <3.2 and >2.2) and sp. ax3–ax4 ≤1.0m	No. of axles and wheelbase ≥3.2m	No. of axles and sp. ax1 – ax2 ≥3.2m and sp. ax2 – ax3 ≤1.0m	No. of axles and sp. ax1– ax2 ≥3.2m and sp. ax2 – ax3 >2.2m	No. of axles and sp. ax1 – ax2 ≤2.2m	No of axles and sp. ax1– ax2 > 2.2.m and sp. ax3 – ax4 > 1.0m
Vehicle types in class	o–o (short vehicle)	o–o–o o–o–oo (short vehicle towing)	o––o (long vehicle)	o––oo	o–o––o	oo––oo	o––o–o––o o–o––oo
% of total HMV[a]	–	–	28	11	3	4	2
Length range (WIM[b] data)	–	–	4–11m	7–12m	6–15m	8–11m	8–19m 10m–17m
RUC[c] class	–	–	2	6	2,24	14	2,30 2,29
TNZ[d] length class	S	S/M	M	M/L	M/L	M	M/L
Austroads[e] class	1	2	3	4	6	5	7
Light/heavy	Light	Light	Heavy	Heavy	Heavy	Heavy	Heavy
Axle groups[f] (pave des)	–	–	1s, 1d	1s, 2	1s, 1d, 1d	1s, 1d, 1d, 1d	1s, 1d, 1d, 1d 1s, 1d, 2
EEM[g] class	Car and LCV	Car and LCV	MCV	HCV1	HCV1	HCV1	HCV1

Table C1 (cont.) TNZ Vehicle classification scheme (adapted from TNZ 2004b))

Feature	Class						
	8	9	10	11	12	13	14
Axles	5	6	6	7	6,7,8	8,9	Everything else
Distinguishing feature or identification algorithm	No. of axles	No. of axles and sp. ax1 – ax2 >2.2m and sp ax4 –ax5 ≤1.4m	No. of axles and sp. ax1 – ax2 >2.2m and sp ax4 – ax5 >1.4m	No. of axles and sp ax1 – ax2 >2.2m	No. of axles (6, 7 or 8) and sp. ax1 – ax2 >2.2m	No. of axles and sp ax1 – ax2 > 2.2m	
Vehicle types in class	o––oo–o––o o–oo––oo	o–oo––ooo	o–oo–o––o	o–oo––oo––oo (B-train) o––oo–oo––oo (T&T)[h] o–oo––oo–o––o (A-train)	oo––oo–o––o oo––oo–o––oo oo––oo–oo––oo	o–oo––ooo–oo (B-train) o–oo–ooo–o––oo (A-train) o–oo–oo–o––oo (A-train) oo––oo––ooo––ooo (B-train)	
% of total HMV[a]	1 3	14	2	4	9	8	
Length range (WIM[b] data)	16–19m 11–17m	15–18m	16–20m	18–21m	15–20m 17–21m 18–21m	19–21m	
RUC[c] class	6,30 6,29	6,33	6,37	6,29,29 6,43 6,29,30	14,30 14,37 17,43	6,33,29 6,33,30 6,29,37 6,33,33	
TNZ[d] length class	L/VL L	L/VL	L/VL	VL	L/VL VL VL	VL	
Austroads[e] class	8	9	9	10	9 10 10	10	
Light/heavy	Heavy	Heavy	Heavy	Heavy	Heavy	Heavy	
Axle groups[f] (pave des)	1s, 2, 1d, 1d 1s, 2,2	1s, 2, 3	1s, 2, 1d, 2	1s, 2, 2, 2 1s, 2, 2, 2 1s, 2, 2, 1d, 1d	1s, 1s, 2, 1d, 1d 1s, 1s, 2, 1d, 2 1s, 1s, 2, 2, 2	1s, 2, 3, 2 1s,2, 3, 1d, 1d 1s, 2, 2, 1d, 2 1s, 2, 3, 3	
EEM[g] class	HCV2	HCV2	HCV2	HCV2	HCV2	HCV2	

Notes to table C1:

a HMV = heavy or medium vehicle (vehicle over 3.5 tonnes gross laden weight)

b WIM = weight in motion: refers to equipment that weighs individual vehicles passing over a measuring plate

c RUC = road user charges

d Within TNZ length class, S (short) = 0–5.5m, M (medium) = 5.5–11m, L (long) = 11–17m and VL (very long) >17m

e Austroads classes 11 and 12 are not relevant in New Zealand

f Within axle groups, 1s = single axle, single tyre; 1d = single axle, dual tyre; 2 = tandem axle, dual tyre and 3 = triaxle, dual tyre

g See table C2

h T&T = truck and trailer

C2 EEM

Table C2 **The EEM's definitions of vehicle classes**

Vehicle classes	Vehicle class composition
Passenger cars	Cars and station-wagons with a wheelbase of ≤3m.
Light commercial vehicles (LCVs)	Vans, utilities and light trucks up to 3.5 tonnes gross laden weight. LCVs mainly have single rear typres but include some trucks with dual rear tyres.
Medium commercial vehicle (MCV)	Two-axle heavy trucks without a trailer and over 3.5 tonnes gross laden weight.
Heavy commercial vehicle 1 (HCV1)	Rigid trucks with or without a trailer, or articulated vehicles with three or four axles in total.
Heavy commercial vehicle 2 (HCV2)	Trucks and trailers, and articulated vehicles with or without trailers, with five or more axles in total.
Buses	Buses, excluding minibuses.

Appendix D Speed frequency plots for all vehicles (full week)

Figure D1 Frequency of vehicle speeds (all vehicles) at the SH57 trial site 410m from the hazard

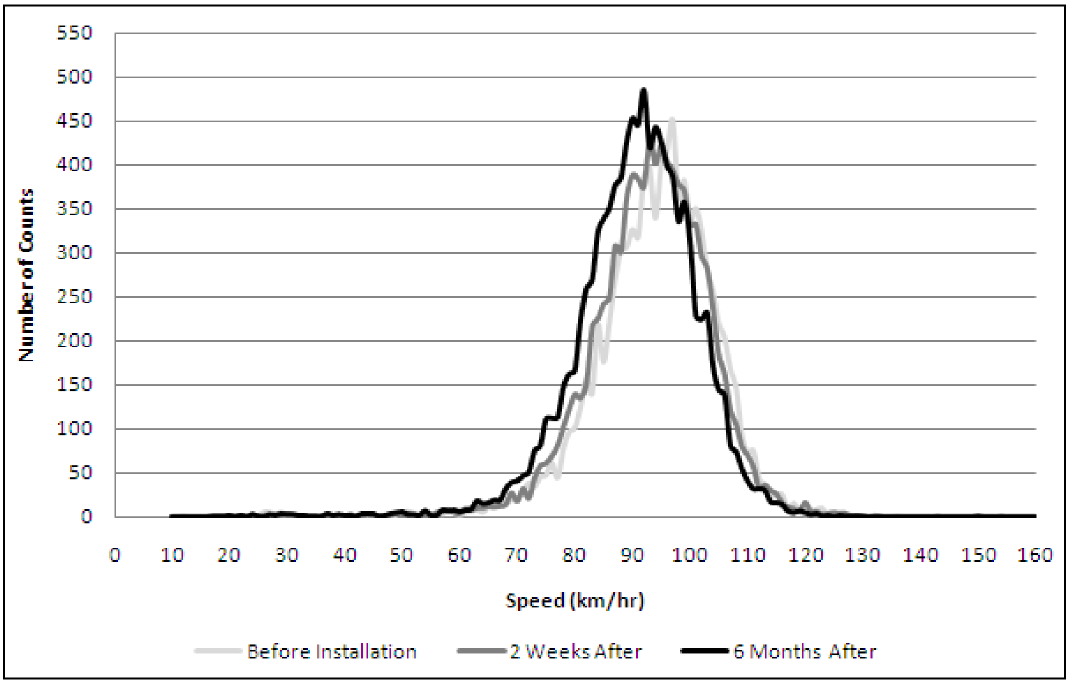

Figure D2 Frequency of vehicle speeds (all vehicles) at the SH53 trial site 410m from the hazard

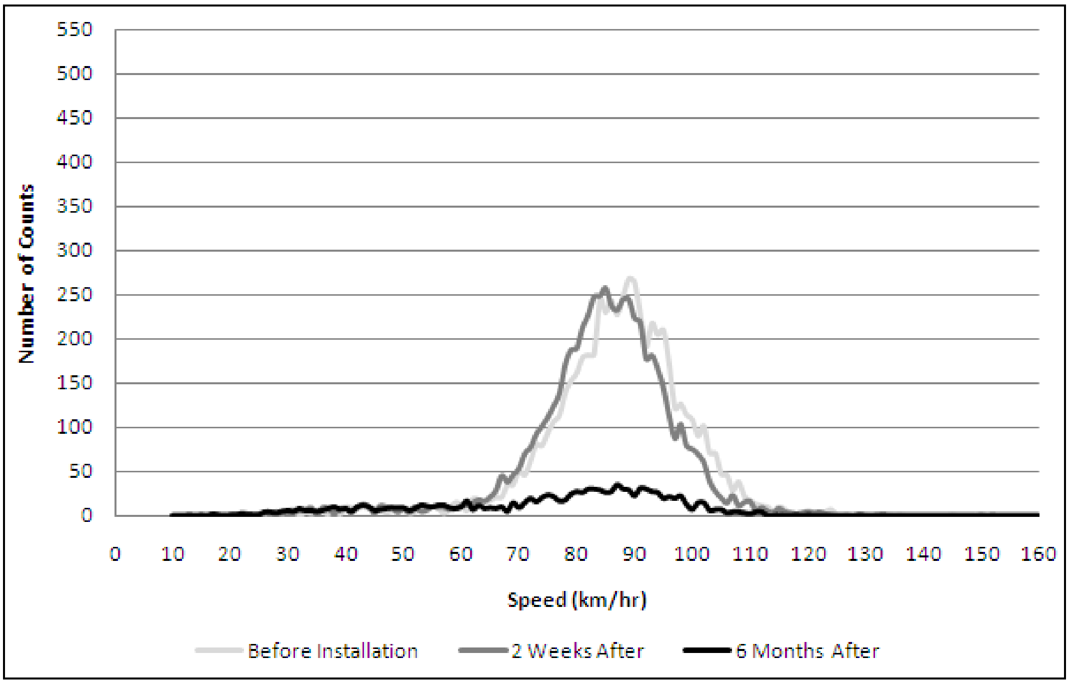

Figure D3 Frequency of vehicle speeds (all vehicles) at the SH57 trial site 260m from the hazard

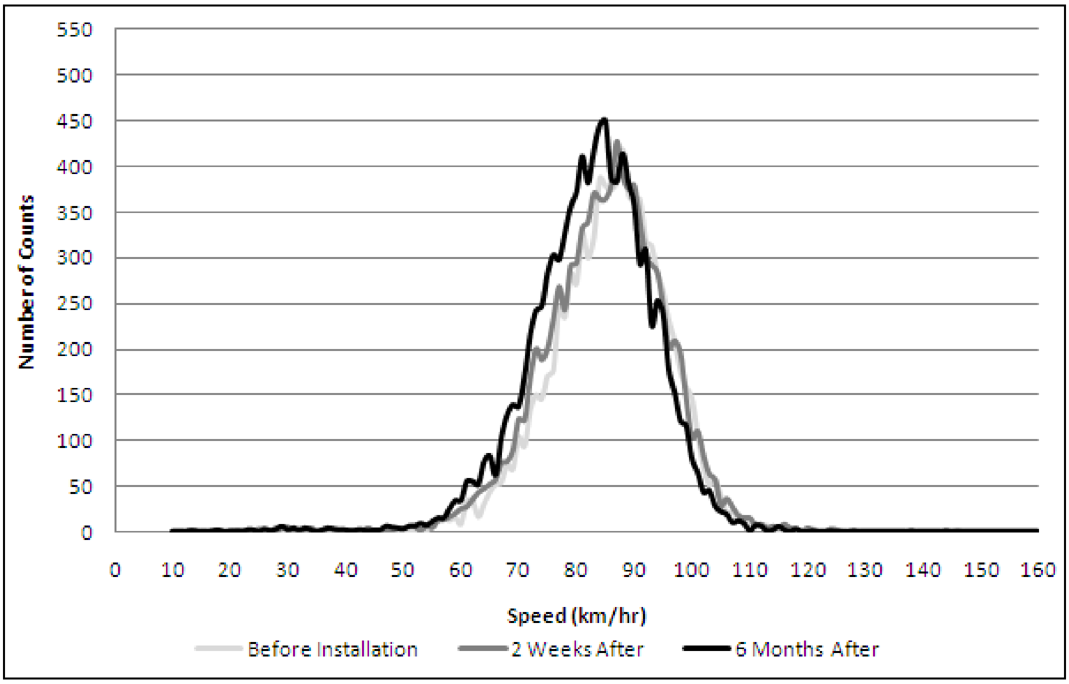

Figure D4 Frequency of vehicle speeds (all vehicles) at the SH53 trial site 260m from the hazard

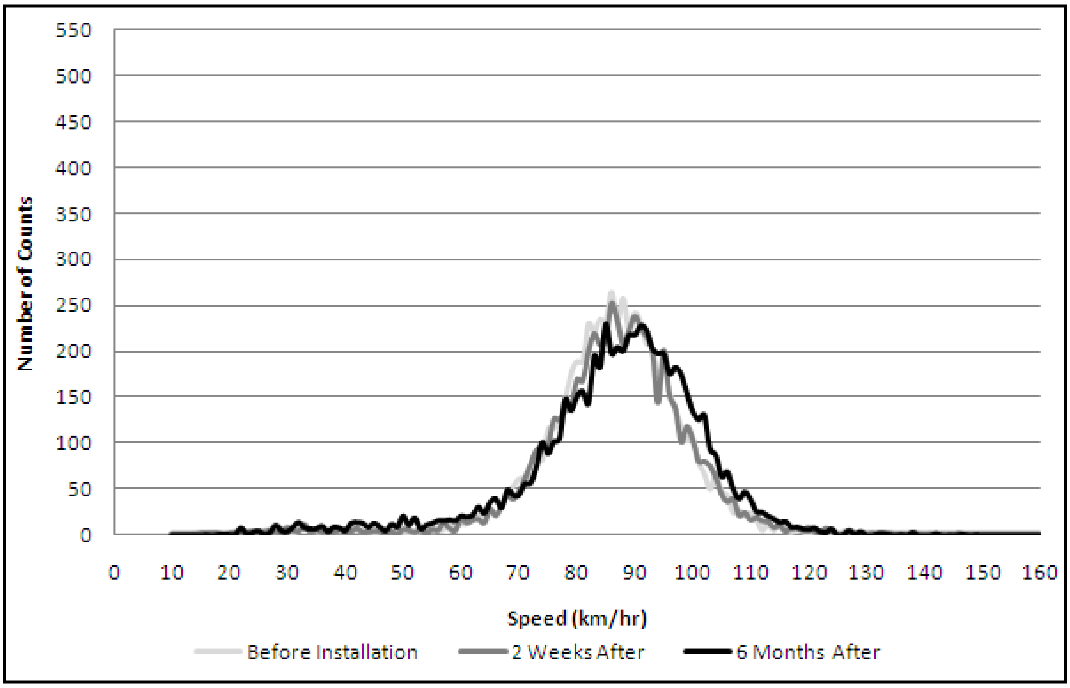

Figure D5 Frequency of vehicle speeds (all vehicles) at the SH57 trial site 50m from the hazard

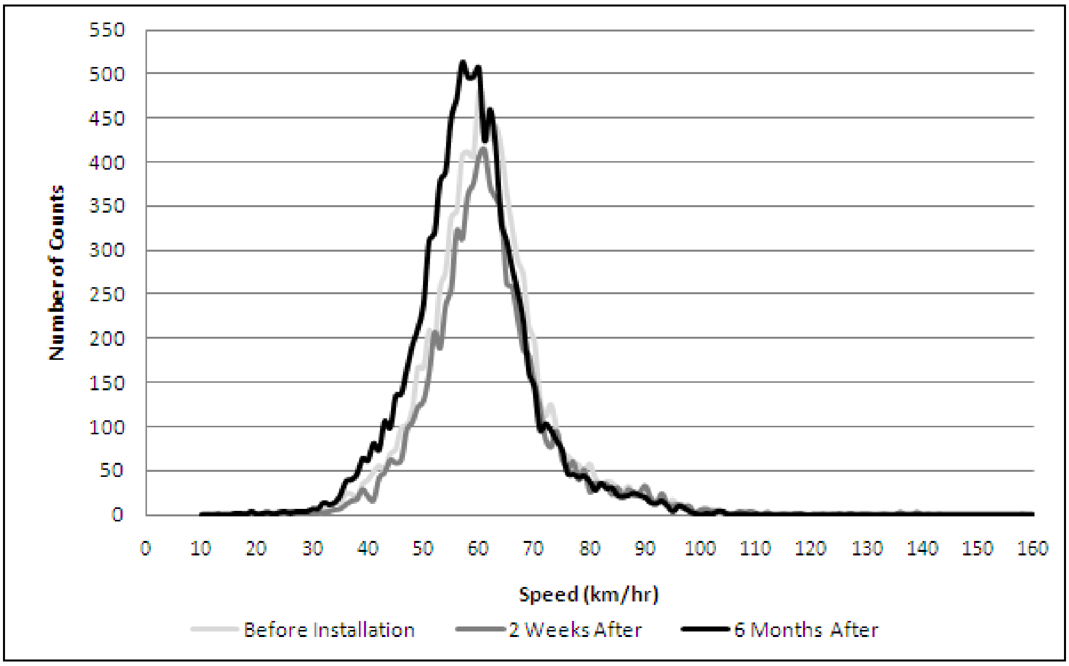

Figure D6 Frequency of vehicle speeds (all vehicles) at the SH53 trial site 50m from the hazard