Trialling best value delineation treatments for rural roads

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An important note for the reader

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Contents

Executive summary

In 2015, nearly 73% of all fatal New Zealand road crashes occurred on rural roads. Nearly half (43.4%) of these rural road fatalities were the result of a vehicle losing control or running off the road, and were more prevalent on corners than on straight stretches. Delineation roadmarkings and devices (such as edge marker posts and raised reflective pavement markers) are common tools used to enhance driving visibility and aid curve navigation, making them critical for reducing these crashes. However, the relative cost of establishing and maintaining this kind of delineation on low-volume rural roads poses a challenge.

To optimise resources across the rural network, any delineation treatment should aim to achieve a balance between cost, safety and customer comfort. Consideration should also be given to the level of exposure within different road hierarchies in order to maximise resource value, where roads with higher volumes of customers receive higher levels of service (eg following the One Network Road Classification).

The present investigation provides updated guidance on the optimum quantities, types and/or configurations of delineation required to achieve a minimum level of service across different rural road hierarchies. Rural roads for the purposes of this report include sealed roads in rural locations with a speed limit of 70km/h or over. There is also a strong focus on low-volume rural roads (ie those with average annual daily traffic of 3,000 or less), where cost-effective delineation solutions are more critical.

Method

The methodology consisted of five main phases: a literature review identifying evidence of international best practice and new technologies (phase 1); on-road trials testing different delineation solutions on rural New Zealand roads (phase 2); a driver survey examining how road users value delineation (phase 3); a discussion of the costs and benefits (phase 4); and a general discussion of the findings with recommendations, including recommended updates of the existing guidelines for rural roadmarking and delineation (RTS 5; phase 5).

On-road trial findings

For the on-road trials, four delineation treatments were tested. All four focused on assisting motorists in negotiating curves on rural roads, with the last three treatments focused on helping motorists in wet weather conditions. The four treatments included 1) the removal of edge marker posts (EMPs) on a straight stretch of road before a curve to trial targeted delineation, 2) the use of a structured marking edgeline on a curve, 3) the use of raised reflective pavement markers (RRPMs) on a curve, and 4) the use of audio tactile profile markings on the edgeline on a curve.

Drivers' hand positions and various vehicle characteristics (such as speed) were recorded for each trial and analysed for their effects according to treatment type. A key success metric for this study was to attempt to test delineation that provides visual conditions that are as close as possible to ideal or dry, daytime road conditions. The underlying assumption is that improvements in driver behaviour in poor visibility conditions could be benchmarked against dry, daytime behaviours.

New evidence from the current investigation revealed that many of the delineation tools used had additional driving navigation benefits, such as EMPs providing cues to distance and speed (as well as long distance cues to road curves). There is also some evidence to support the use of delineation variation to intuitively guide drivers to be more attentive to higher risk locations, following the concept of self-explaining roads. Finally, in terms of wet weather treatments, new material applications (such as structured markings) resulted in better performance in rainy conditions. However, the combination of a traditionally applied, good quality roadmarking with RRPMs is still more cost effective for rural settings, especially if the marking is on a high-grade chipseal (ie large stones), that already holds a high profile and good drainage (as opposed to a worn road surface).

Conclusions

As a visual guidance tool, delineation devices have the ability to improve poor visibility environments (such as night or rain conditions) in such a way to enable drivers to preview the road ahead as if they were driving in as good as dry day conditions. Developing a best value delineation approach is all about understanding the effectiveness of different delineation solutions, so safety, cost, journey time and comfort can be optimised across the network.

Based on the effectiveness of delineation on driver behaviour and safety, more effort should put into the standardised monitoring of specific types and qualities of delineation; and better monitoring and understanding of the contribution of the pavement surface to the effectiveness of the delineation treatment. Such initiatives should set a higher standard of performance on roads that have higher importance (ie for New Zealand following the One Network Road Classification system), or have higher exposure to poor visibility conditions (ie high annual rainfall). Actions of this kind would further our understanding of how to best optimise delineation performance, though would still require a shift from the culture of performance monitoring, from focusing on confirming observed underperformance to proactive mapping of asset performance using meaningful measures (such as sight distance). Initiatives of this kind are particularly relevant and sit at a critical stage of change, given there is an ageing population, as well as the rapid emergence of new technology that could utilise delineation if it were simply more consistent (ie autonomous vehicles).

Recommendations

The following recommendations are made based on the findings from this research:

- EMPs are cost-effective, all weather, delineation tools that have safety value and should be used on all road hierarchies (on straight stretches and curves). This study provides unique information that supports their use as critical guides in night-time driving conditions as they are evenly spaced at 100m gaps and hence, enhance judgement of speed and distance. Removing them from straight stretches of road would have unexpected and negative influences on speed.
- Develop national guidance for consistent delineation treatments to support self-explaining road designs. This is where the driver is intuitively cued to an increase in actual risk through an increase in delineation, giving the driver explicit signals to adapt their behaviour (eg by increasing their attentiveness or reducing their speed). Such guidance could align with existing road categorisations, such as ‘curved’, ‘winding’ and ‘tortuous’ sections of road, based on the One Network Road Classification. This is also relevant for rapidly emerging technology (such as autonomous vehicles).
- The RRPMs are a cost-effective, inclement weather solution that should be used increasingly on most rural roads, especially in areas with increased exposure to wet weather and wet weather crashes. They add complementary safety value even to high-quality markings (at least in the early phase of their life cycle).
- RRPMs also prove that a highly retroreflective point source delineation treatment adds increased visibility to a traditional continuous line treatment when driving in the rain. Further work could examine point source treatments either without continuous roadmarkings, or with less frequently maintained roadmarkings.

- Though the structured markings appeared to improve visibility for drivers in rainy conditions, there were issues with the particular marking trialled. As a result, the physical performance properties (retroreflectivity and luminance) were not high, presumably due to bead loss. Further testing is recommended.
- Tangent point delineation solutions should be trialled at curves. Delineation is targeted to the inner curve where drivers look when they judge curve tightness. This means for a left-turning curve, the left edgeline and centreline at each curve could be re-marked more regularly than the less viewed right edgeline, which could reduce costs by about a sixth (if re-marked every second rotation). Alternatively, better materials or wider markings could be tested using this targeted approach.
- There is some evidence of a gap between actual behavioural performance when driving in the rain and retroreflectometer readings in wet conditions. This should be examined more closely, as it appears the human eye detects some markings better than expected in rainy conditions. There is potential for identifying further improvements for new delineation treatments as well as possible cost savings.
- The evidence here suggests techniques to provide a textured road surface (like the 2/4 aggregate used in trials) also appear to have additional visibility effects, providing not only better grip and drainage, but also better wet weather delineation performance. These added effects could be considered in road surface decision making.
- Consideration should be given to providing better communication plans and increasing transparency with the public around any removal or reduction in levels of service for high-visibility infrastructure (such as delineation). The findings suggest public backlash can be mitigated if the public understands why there has been a shift in spending. A proactive communications plan allows the development of a public profile of the safety interventions being focused on, and why this is important to optimise area-wide safety at the local level.

Abstract

Providing a safe, comfortable, cost-effective visual environment to help drivers navigate rural roads requires a better understanding of the strengths and limitations of different delineation devices, materials and treatment configurations. An international literature review examined different options to test on low-volume rural New Zealand road settings, and an expert panel prioritised four of these options to be trialled.

Four on-road trials were run to examine delineation configurations and materials that could provide better value for rural roads. The key aspects to deciding treatments were to do with targeted delineation (to assist drivers in intuitively signalling more difficult parts of the road network), consolidation (where one configuration with a new product might replace two traditional products), and better delineation in rain, which is arguably a common poor visibility environment (where crashes are over represented). The findings provided new information about the importance of complementary devices, including edge marker posts and raised reflectorised pavement markings in different contexts. Finally, to help implement better delineation solutions on lower volume rural roads, the report offers practical updates of the rural road delineation guidance (RTS 5).

1 Background

In 2015, 72.9% of all fatal road crashes in New Zealand took place on rural roads (MoT 2015). Nearly half (43.4%) of these rural road fatalities were the result of a vehicle losing control or running off the road, and were more prevalent on corners than on straight stretches. Delineation roadmarkings and devices like edge marker posts (EMPs) and raised reflective pavement markers (RRPMs) are common tools used to aid driving visibility and navigation, and are critical in reducing these crashes. However, the relative cost of establishing and maintaining delineation on low-volume rural roads provides a challenge in terms of being cost effective.

Transit NZ (now the New Zealand Transport Agency, referred to in this report as 'the Transport Agency') published the RTS 5 guidelines for rural roadmarking and delineation in 1992 (Transit NZ 1992) as an aid to identifying best practice solutions, and establishing a hierarchical approach to prioritising different levels of delineation. However, this has not been altered since. Subsequently, substantial improvements have been made in roadmarking materials and practices, in addition to vehicle safety improvements, meaning an update of the guidelines is pertinent. In a review of road controlling authority standards and guidelines in New Zealand, Jackett (2006, p13) points out that a review of RTS 5 is overdue, with a particular desire for guidance on 'getting the right balance of resources for delineation on rural roads'.

In terms of optimising resources across the rural network, any delineation treatment should consider the right balance between cost, safety, journey time and customer comfort. Best value also needs to consider exposure within different road hierarchies, where roads with higher volumes receive higher minimum levels of service (eg following the One Network Road Classification).

This research has provided updated guidance on the right quantities, types, or configurations of delineation to achieve a minimum level of service across different rural road hierarchies. Rural roads for the purposes of this report include sealed roads in a rural location with a speed limit of 70km/h or over.

The purpose of this project was to get the right balance of delineation on rural roads, with a focus on best value for the road user (or customer). A key activity was to follow a novel evaluation methodology that identified the value users obtained from delineation in terms of cost, safety, travel time benefits and comfort. To achieve this, the project identified and trialled treatments to see how delineation options could be simplified or reconfigured using new and existing materials. Ultimately this would enable improved guidance for road controlling authorities to deliver best value delineation on their rural road networks.

2 Methodology

2.1 Overview

The methodology for the overall project consisted of five phases:

1. **Literature review and treatment selection:** Reviewed and evaluated the relevant national and international literature, best practice research and new technologies which had been or could be applied in New Zealand. This review identified several delineation treatment options of which four were selected for on-road trials based on the advice of an expert panel.
2. **On- road trials:** The four delineation treatments were trialled at three different locations (with the final two interventions located at the same site). The trials focused on helping motorists negotiate curves, with the final three treatments focused on assisting motorists in wet weather conditions. The four treatments trialled were:
   a. the removal of EMPs on a straight stretch of road before a curve
   b. the use of a structured marking edgeline on a curve
   c. the use of RRPMs on a curve
   d. the use of audio tactile profile (ATP) markings on the edgeline of a curve.

   Intervention treatment success was evaluated through changes in key driver behaviours, including measures such as hand positions, following distance and speed.
3. **Driver surveys:** The licence plate numbers of vehicles travelling through the first trial site were recorded and the registered owners of these vehicles were then posted a survey to complete to better understand road user perceptions of delineation.
4. **Costs and benefits:** A discussion of the costs and benefits of various treatments using the results of the trials and survey was carried out.
5. **Recommendations:** Drawing on the outcomes of the previous four phases, recommendations for updating the guidelines for rural roadmarking and delineation (RTS 5) were developed and reviewed by an expert panel. The entire report was then externally reviewed to ensure a high quality final report for submission to the NZ Transport Agency.

2.2 Literature review and treatment selection

2.2.1 Literature review

The purpose of the review was to identify new technologies and evaluate simplified or consolidated systems to trial on the New Zealand road network, with a view to influencing changes to improve road delineation and marking standards. The scope was limited to roadmarkings and delineation practices on rural roads. Rural roads are classified as those roads with a speed limit of greater than 70km/h and include state highways and roads administered by territorial authorities.

The meaning of the word ‘improve’ in this context is to assist in progress towards a safe road system in which death and serious injury are minimised. The review was written from a Safe System perspective, meaning a philosophy of working, within the funds available, towards a road system where serious injury and death has been reduced.

2.2.2 Treatment selection

Treatment options were focused on cost-effective solutions that could be examined within the road network to provide safe, efficient markings to satisfy the customer. Successful new forms of delineation and delineation combinations favoured by other countries with a proven safety history were examined.

Currently, EMPs, pavement markings and RRPMs are the main devices used in New Zealand. Drawing from the literature review and discussions with steering group members, a number of treatments were identified, short listed and prioritised to ensure the best practical and innovative options were tested within the research. In addition to new technologies, cost-effective combinations and simplified systems were examined. Table 2.1 describes the experimental conditions tested in the study.

2.3 On-road trials

To understand the performance of each delineation treatment option and the potential implementation combinations, a series of on-road trials were conducted in Masterton and Palmerston North, New Zealand. The performance of the delineation treatments was measured in real-world settings to bolster the validity of the findings.

2.3.1 Final treatment options

Depending on the delineation treatment being trialled, sites were examined under different visual conditions, with trial 1 focusing on daytime and night-time conditions and trials 2 to 4 on wet conditions. All trial treatments were implemented at curves, as this allowed a better test of lane keeping and the need for delineation. The trials were not conducted on excessively sharp curves, so the part of the network to which on which the treatments were implemented would be that described in the One Network Road Classification as ‘curved’.

Table 2.1 Delineation treatments trialled

<table>
<tr><th>Site</th><th>Experimental condition</th><th>Purpose</th></tr>
<tr><td>Trial 1
(Masterton)</td><td>Targeted EMPs</td><td>Targeted delineation: To test whether a relative increase in delineation in higher risk environments (ie at curves) helps drivers intuitively adapt to a change in risk (following the concept of self-explaining roads). This was tested by removing EMPs on the straight section of road prior to the curve.</td></tr>
<tr><td>Trial 2
(Palmerston North)</td><td>Structured edgeline markings</td><td rowspan="3">Wet weather delineation: To test which delineation treatments and configurations best help drivers in impaired visibility conditions due to wet weather (where crashes are over represented). The treatment conditions provided variation in:
• delineation height (or clearance from the road)
• retroreflectivity (including the use of specialist beads)
• a continual line compared with multiple individual point sources (ie with gaps between them like RRPMs).</td></tr>
<tr><td>Trial 3
(Palmerston North)</td><td>RRPMs beside traditional edgeline roadmarkings</td></tr>
<tr><td>Trial 4
(Palmerston North)</td><td>ATP edgeline roadmarkings</td></tr>
</table>

2.3.2 Measures

The material performance of the four delineation treatments was measured by using methods such as retroreflectivity. Driver behaviour was observed naturalistically, using key performance measures such as speed, lane position and hand positions. Table 2.2 provides an overview of the measures which were collected at each test location.

Table 2.2 Measures taken on site

Measure	Description
Driver hand positions	On-site observers visually evaluated the hand positions of passing drivers as a proxy measure for driver satisfaction. Fewer hands on the top half of the steering wheel indicated a lower level of perceived risk in the driving environment, and therefore an easier (and more enjoyable) driving task (eg see Walton et al 2011).
Vehicle speed	Vehicle speed relates to both safety and driver comfort. The average, median, 85th percentile speed, and speed non-compliance (with the speed limit) were captured.
Vehicle type	This was collected to allow examination of light vehicles in isolation (as other vehicle types such as trucks have different speed and lane position profiles).
Vehicle headway	Headway or following distance between two vehicles was calculated (but only for vehicles following within four seconds of another vehicle). Headway is used as a proxy measure of risk, where lower headways can indicate a more uncomfortable driving environment (eg Lewis-Evans et al 2010).
Lane position (Trial one only)	Lane position was assessed to determine vehicle position in relation to "desirable" driving paths, as well as any lane encroachment.
Driver perception survey (Trial one only)	Self-regulation around road environments (including limiting exposure to night or wet conditions), general driving satisfaction measures (including delineation), specific satisfaction with delineation, and willingness to pay for improved night and wet weather delineation (see section 2.4 for more detail).
Retroreflectivity (Trial two only, for the structured marking and ATP marking trials)	A retroreflectometer was used to measure delineation properties of the roadmarkings during wet conditions.

2.3.3 Data quality assurance

2.3.3.1 Speed data

Speed data was filtered to ensure the data analysed related to free speed (at least a four-second headway to the immediately preceding vehicle).[1] Heavy vehicles (such as trucks) were removed from analyses.[2]

The speed data was also filtered to include only speeds of 60km/h or above for the analysis. This threshold was selected because at the one site with no turn-off points or immediate driveways, there were no recorded speeds below 60km/h. At the two remaining sites, where there were turn-off points, about 2.7% of the vehicles were travelling at speeds below 60km/h, and so were removed from the data. The highest speed recorded at any location was 143km/h. No top speeds were removed from the sample.

[1] Unusable data occurred on the Metrocounts at locations 1 and 3 in 2.7% of instances, for example due to two vehicles crossing at the same time from opposite directions. Unusable data was not included.

[2] When analyses were run on heavy vehicles there were no significant differences for mean speed (the numbers were too small to examine headway within this group).

2.3.3.2 Headway data

The data for headway analysis was filtered to include only headways of four seconds or less, to indicate a following vehicle. Headways of two seconds or less were used as a compliance measure, as a two-second threshold has been identified as critical in terms of increased risk and discomfort (eg Lewis-Evans et al 2010).

2.3.3.3 Hand position data

Two observers were used to examine driver hand positions to ensure high inter-rater reliability between observers (inter-rater reliability was above 90%).

2.3.3.4 Retroreflectivity

Multiple measures were taken at each site, both in terms of multiple readings at a specified location, and also at multiple locations within each treatment condition.

2.3.4 Equipment

2.3.4.1 Driver hand position

Driver hand positions were recorded by observers standing on scaffolding positioned beside the road at each trial site (where possible unobtrusive positions were selected in an effort to gain the best view of the driver while minimising the likelihood of the observer's presence altering driver behaviour). For trials at night, observers recording hand positions used a mixture of night vision googles, binoculars and monoculars in conjunction with infrared lamps to illuminate vehicles as they passed through the site.

2.3.4.2 Vehicle speed, headway, lane position, and direction

For trial one, CEOS's 'the infra-red traffic logger' (TIRTL) was used to capture vehicle speed, type, headway, lane positon and direction of travel through the site (eg northbound or southbound).[3] TIRTL uses two infra-red light beams passing above the road surface to detect and record vehicle characteristics. This was supplemented with vehicle speed, direction, type and headway captured using standard Metrocount tube counters.

For trials two, three and four only Metrocount tube counters were used, which meant collected data was restricted to vehicle speed, direction, type and headway.

2.3.4.3 Retroreflectivity

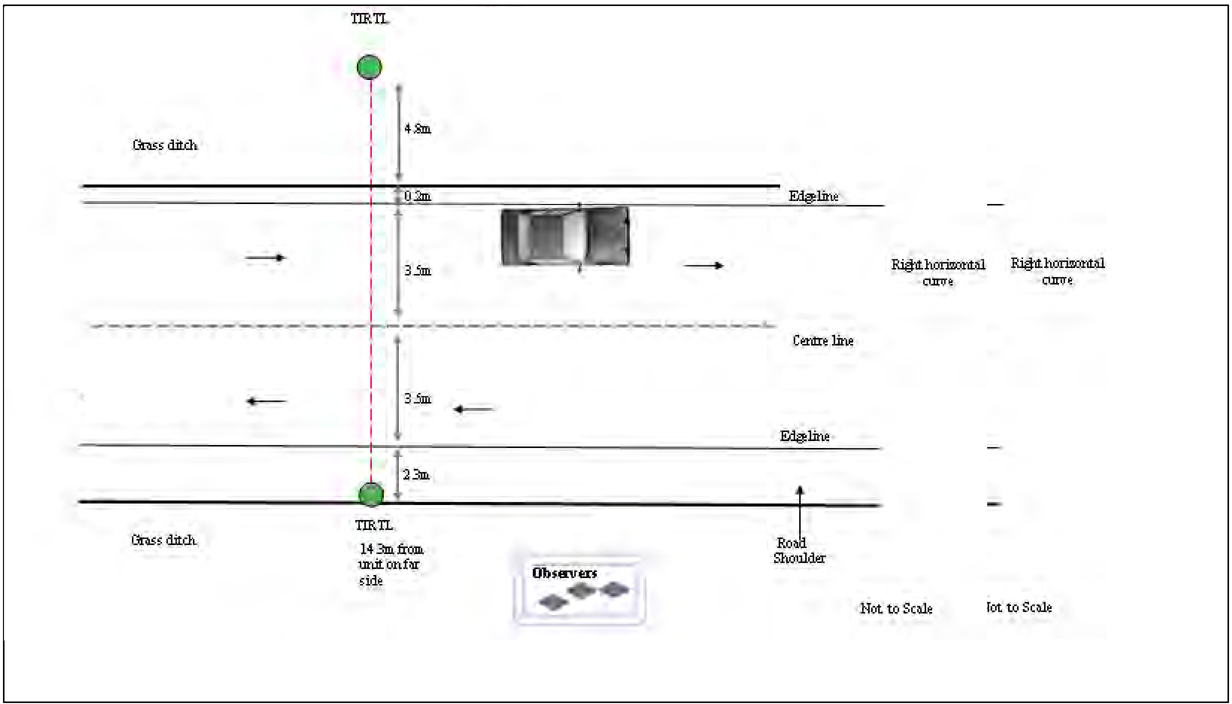
For trial two only, a Zehntner testing instruments 6310 retroreflectometer R_L/Qd was used to record the retroreflective luminance of the structured markings.

2.3.4.4 Example site setup

Figure 2.1 shows the example site setup for trial one using the TIRTL (to capture speed, headway, lane position, vehicle type), and the position of the observers when collecting the hand positions of drivers as they pass by. The observer position shown provides an optimised view into the vehicle, where observers are in an elevated position (using scaffolding from a position hidden behind trees as the vehicle approaches, but with a clear view to the road when the vehicle is adjacent).

[3] The TIRTL was calibrated against the Metrocounter in a controlled test to ensure the speed data was accurate.

Figure 2.1 Site setup for the TIRTL and observers collecting hand position data at location 2 immediately preceding the curve



2.4 Driver survey

In addition to the on-road trials, a survey of drivers passing through the trial one site was conducted. This survey directly examined driver satisfaction with the trial treatments, supplementing the proxy measures for driver satisfaction included in the naturalistic observations. General questions also examined satisfaction with delineation in relation to other customer level of service indicators, such as road pavement quality. The survey was only conducted at the trial one site, primarily as there was specific interest in public reaction to the removal of delineation devices. Trials two to four either replaced or added delineation.

2.4.1 Sampling and survey method

A sample of drivers who had driven through the trial one site were sent questionnaires to further examine their perceptions and satisfaction with delineation on rural roads. The drivers were identified by their number plates and received a version of the survey with a cover letter explaining the purpose of the study and how they were selected for participation. A prize draw offering vouchers of the participant's choice was used as a small incentive to encourage participation in the survey and to show appreciation for their time to complete it. The response rate was 31%.

2.4.2 Survey question areas

Key measures included in the study are detailed in table 2.3.

Table 2.3 Key measures in the driver survey

Measure	Description
Demographics	Age, gender, visual impairment presence, years of driver experience, and self-regulation around road environments (eg the extent to which, if any, the driver limits their exposure to specific driving situations).
General driving satisfaction measures	Satisfaction with lane width, road pavement quality, quality of pavement markings, signage, overall travel speed, congestion, roadside landscaping, driving behaviour of other drivers and overall design for safety. Measures taken from existing national measures of satisfaction with the general road environment, from sources such as the National Highway Survey which captured driving satisfaction of topics such as road safety design, surface quality and environmental factors (Transit NZ 2006)
Site-specific satisfaction measures	Measures that focused on visual road qualities, with drivers being prompted via images of the site they were observed driving through.
Willingness to pay measures	A willingness to accept a different travel time method was employed. This forced drivers to trade off travelling on routes with improved delineation treatments against increased travel times. This allowed for satisfaction with delineation to be assigned an EEM value based on travel time (see appendix A)

2.5 Cost-benefit analysis

A cost–benefit analysis examined the relative cost of different delineation treatments against safety, using proxy measures such as speed and driver satisfaction (including travel time and stated preferences using surveys).

- **Safety:** Looked at potential changes in crashes using Crash Analysis System (CAS) data. Then used value of life costs to determine any cost or benefit.
- **Travel time changes:** Looked at any positive speed benefits from delineation (ie able to alter speeds to more comparable dry daytime speeds, but not excessive speeds).
- **Stated preference for delineation:** A willingness to accept different travel time method was employed. This forced drivers to trade off travelling on routes with preferred delineation treatments against increased travel times. This allowed for satisfaction with delineation to be assigned a value based on travel time (see appendix A).

3 Review of literature and current practices

3.1 Comment on the quality of previous research and literature

There has been no formal attempt to assess the quality of the literature available on optimising delineation treatments for rural road conditions. However, the work available is of very mixed quality, with work known to be rigorously peer reviewed in the minority. Many documents reviewed were reports commissioned by government organisations or conference papers, which may or may not have been rigorously reviewed. This means the certainty attached to the findings is less than ideal. In addition, some of the literature related to work carried out on roads where the information supplied made it difficult to match the context of the work to the New Zealand road network. There are also many real-world studies where key parameters about influential road characteristics, such as road width, are not identified, which could explain inconsistent results. These factors highlight the need to carry out well-targeted trials on the New Zealand road network.

3.2 The purposes of various delineation devices and markings

Each form of roadmarking or delineation is designed for a particular purpose or purposes, such as short or long-range visibility, and most are effective during the day or night or in wet or dry conditions. However, some forms serve more than one purpose, ranging in their effectiveness for these purposes. In order to consider consolidation of the various elements, it is important to be clear about the purpose of each and its limitations.

3.2.1 Edge marker posts

EMPs are designed primarily for night-time/poor visibility use to provide long-range guidance on the road alignment (Transit NZ 1992). They are especially useful for providing visibility on sections of roads with horizontal and vertical curves, in addition to assisting drivers identify hazards (eg road narrowing, bridges and culverts). Due to the location of the EMPs (to the left of the vehicle) their visibility is not greatly affected by oncoming traffic. However, they are subject to failure in an unpredictable fashion through age, vandalism and crashes.

3.2.2 Edgelines

Edgelines and all longitudinal pavement markings provide a continuous stream of information about the roadway ahead. They alert the driver to changes ahead and help the driver maintain lateral positioning within the lane. They generally provide short-to-medium-range delineation and provide guidance that is less affected by oncoming traffic at night. As with all non-raised pavement markings, visibility may be degraded in wet conditions.

3.2.3 Centrelines

Centrelines are used to define the portion of a two-way sealed roadway available for travelling in each direction (Transit NZ 1992). Centrelines encourage vehicles to correctly align on their side of the road and can discourage crossing to the other side. They provide effective short-to-medium-range delineation during the day and night; however, they are affected by oncoming traffic and visibility is often poor in wet conditions. In conjunction with edgelines, they assist lateral alignment within the lane (eg Davidse et al 2004).

3.2.4 Raised reflective pavement markers

RRPMs are usually combined with painted markings to alert drivers to alignment changes in the road ahead. RRPMs are an intermittent delineation tool with good visibility in wet weather and during darkness. They also provide long-range guidance of the route in addition to short-range lane positioning in the presence of oncoming traffic. Additionally, dependent on spacing, they can provide an audio-tactile lane departure warning.

3.2.5 Audio tactile pavement markings

ATP markings, also known as rumble strips, are designed to alert sleepy or inattentive drivers from veering away from their intended path by transmitting an audible and tactile vibration when driven on. These are designed to augment edge or centreline markings and provide increased visibility at night due to their raised profile. They are generally laid on top of existing markings in New Zealand at an installation height of 10–12mm, with a minimum height of 5mm required to achieve the desired effect (Dravitzki et al 2012). Rumble strips have been shown to have considerable safety benefits when installed on the roadside or in the centre of the road (eg Hatfield et al 2009).

3.3 Driver performance and behavioural measures

3.3.1 Sight distance and driver requirements

Drivers rely on delineation to provide a short-range view for lane keeping, and a longer-range view of upcoming changes in the road geometry. Sight distance (or preview time) of upcoming changes in road geometry is a key measure for driver performance. Sight distance is the number of seconds of the road ahead that a driver can see (taking into account the typical speeds for that section of road). A variety of studies have examined minimum sight distances, typically based on driving simulation studies. Table 3.1 shows a summary of typical sight distances and their influence on drivers (Debaillon et al 2008; European Commission Directorate General Transport 1999; Land and Lee 1994; Smiley et al 2004).

Table 3.1 Typical expected driver responses to different sight distances

Driver responses	Minimum sight distance (seconds)
Driver comfortable	3–5
Drivers begin to adapt (reduced driver speed and variation in lane position)	1.8–2.7
Typically successful horizontal curve negotiation	1.8
Drivers begin to fail horizontal curve negotiation	1.2–1.8

Zwahlen and Schnell (2000) provide an excellent review of sight distance considerations and make a recommendation of 3.65s as a preferred minimum. This figure also allows for a 0.65s fixation time, which is the 85th percentile fixation time observed by eye tracking studies, where the eye fixates and processes information from a delineation device at the maximum possible sight distance.

3.3.2 Driver adaptation and safety

Drivers are most conservative on roads with no delineation, thus suggesting these are the greatest perceived risk. This is particularly evident in adverse visibility conditions: night and wet/rain. Masliah et al (2007) found drivers, to some extent, compensated for lower levels of retroreflectivity by reducing speed. This effect can confound studies attempting to improve safety, as drivers can adapt to some highly visible improvements to the road network, for example by increasing their speed. However, it is known that full adaptation does not take place, as vehicle crashes do occur at higher rates in reduced visibility conditions (see section 3.9).

In the context of this study, delineation providing visual conditions that are as close as possible to dry, daytime road conditions is ideal. Improvements in driver behaviour could therefore be benchmarked against dry, daytime behaviours. Shinar et al (1980) found speeds increased when edgelines were added, but the authors considered this a positive finding, as the speeds were still slower than those of daytime conditions and the increase towards speeds that mimic daytime behaviour was considered a measure of improved driver comfort and confidence. Similarly, Ranney and Gawron's (1986) simulator study found speeds increased with the presence of an edgeline, but excessive speed (beyond the speed limit) reduced, as did driver workload.

3.3.3 Behavioural performance measures

Traditionally, the successes of changes or enhancements to road delineation and markings have been ultimately quantified using before-and-after crash statistics (eg Evans 2004). This has been particularly relevant where these changes or enhancements are brought about through safety concerns. However, due to the relative infrequency of major or reported crashes the period of reporting is often years, with many confounding factors arising that may influence results. Shorter-term, intermediate success measures for road safety include lateral lane positioning, target speed consistency, headway, hand positions on the steering wheel, driver workload and driver satisfaction.

Driver workload has been measured as another proxy for road safety. Tsyganov (2006) monitored heart rate as drivers negotiated a course before and after edgelines were installed. They found mean night-time workload was reduced by 12% after the addition of edgelines. It has been suggested that at night drivers benefit from clearer roadmarkings (wider providing greater retroreflectivity) by providing easier detection and hence less cognitive effort (McKnight et al 1998).

The 'hands-on' method is a recent method developed in New Zealand (Walton and Thomas 2005; Walton et al 2011) that uses observations of hand positions on the steering wheel to determine a measure of perceived risk of driving. It is based on the premise that drivers have greater control over their vehicle when they place their hands in the 10 o'clock and 2 o'clock hand positions on the top half of the steering wheel and drivers are more likely to adopt this position when driving in a more difficult environment. It is sensitive to the overall environmental conditions present at the time of measurement, such as weather, traffic conditions, speed zone and roadmarkings. It supplements speed and lateral lane positioning to appraise driver comfort or perceived ease of task.

Walton et al (2011) found drivers exhibited the highest perception of risk when it was raining, as evidenced by more cautious hand positioning on the steering wheel. Drivers were 2.5 times more likely to place both hands on the top half of the steering wheel when it was raining compared with driving in dry, night-time conditions. This result is consistent with actual risk in wet conditions based on crash analyses (eg Johansson et al 2009). The authors suggest delineation solutions for wet conditions should be given priority over solutions for night-time conditions based on their wet weather findings (Walton et al 2011).

3.4 Delineation in New Zealand

Delineation of rural roads in New Zealand is based on a hierarchical system, dependent on traffic volumes, importance of the route and road width. This is laid out in the *Manual of traffic signs and markings* (NZ

Transport Agency 2010). Delineation is provided by EMPs, centreline roadmarkings, edgeline roadmarkings and RRPMs in ascending order. The lowest-rated roads may have no delineation at all and at times these guidelines may be varied, often due to safety concerns. In addition, the use of ATP markings has been added as augmentation to the system (and is not included in the RTS 5). The current system uses a process of 'adding to existing' to improve road safety and driver comfort.

The impact on safety of roadmarkings and delineation may be evaluated by using various methods related to crash statistics or by using intermediate outcome measures like speed, lateral position, or the position of driver's hands on the steering wheel. The before-and-after studies use various methods to achieve some degree of control around delineation intervention testing, by keeping all other environmental site characteristics in a complex real-world location consistent. It is difficult to control for numerous confounding issues, such as a general increase or decrease in crashes, changes in reporting behaviour, police presence, changes in travel associated with delineation changes and the effect of the entire delineation system. Owing to the relative rarity of crash events such before-and-after studies may have little statistical power and may come up with null results where possibly if there had been more data available, the null hypothesis might have been rejected (Dravitzki et al 2006). However, where the safety literature has been surveyed (eg Baas et al 2004) the consensus of the research literature indicates a safety benefit.

Research attempting to quantify benefits to driver comfort and travel time of an altered delineation system is relatively sparse. However, these measures are highly important (in addition to the more traditionally included measures) because they may affect driver behaviour and safety indirectly. It could be argued that a driver comfortable on a road and able to travel at an appropriate speed is less likely to take risks and consequently the road will be safer (eg Dravitzki 2005; Goldenbeld and van Schagen 2007).

Roadmarkings and delineation are required to identify the route and continuously advise drivers of potential hazards with the aim of making it as easy as possible for drivers to navigate the road ahead. The tools used are designed to enhance driver satisfaction, shorten drive time and improve the safety of the road system. Each tool employed fulfils a somewhat different purpose, on a supplementing-the-existing basis. Additionally, the tools are required to be visible in a variety of environmental conditions; including during day, night, wet and dry conditions. Ideally each type of delineation would be effective in all conditions; however, this is not necessarily the case.

3.5 Thresholds for the use of roadmarkings and delineation devices

The RTS 5 guideline on delineation and markings (Transit NZ 1992) recommends that in general delineation devices should not be used on roads where the volume of traffic is less than 100 vehicles per day, with possible exceptions where the following circumstances apply:

- frequent horizontal and/or vertical curves
- sub-standard curves
- sections where the crash record indicates a need (ie where the proportion of lost control, head-on or crashes in darkness are well above the national average)
- continuity on a route or with an adjacent road is desirable
- areas commonly subject to fog, mist or steam
- a high proportion of night traffic flows

- a high proportion of tourist traffic flows.

The RTS 5 guideline recommends the use of only edgelines and dashed centrelines at volumes lower than 750 vehicles per day, with these restricted to 'isolated sections at volumes lower than 250 and 100 vehicles per day'. On unsealed roads, EMPs are recommended at greater than 500 vehicles per day and on 'isolated sections' only at down to 100 vehicles per day. The rationale for this limited use of devices is that, in general, on low-volume roads warning signs are adequate for advising drivers of unexpected changes in road conditions that, if not warned, could be hazardous.

This is in line with the thinking of Dravitzki et al (2003) who indicated that at night there is usually sufficient definition of the roadway from the road surface, vegetation and so on, for a vehicle to be driven successfully (as long as the driver drives to the conditions), even on narrow and winding roads. Were this not so, the many minor rural roads in New Zealand would be much more dangerous than their records show. Thus the major information drivers require under these circumstances is a warning of changes in road conditions.

As traffic volume increases, providing the 'do minimum' (no delineation) option results in:

- increased travel times from slower driving as a result of reduced visibility
- increased vehicle operating costs from acceleration/deceleration
- increased crashes from reduced visibility not adequately compensated for by speed reductions
- increased driver fatigue from driving at higher levels of risk
- decreased driver comfort and satisfaction.

Providing delineation can overcome many of issues indicated above. The critical point is to establish where in the spectrum of rural roads and road volumes the cut-off point lies so that the appropriate levels of delineation can be provided. In the case of low-volume roads, the New Zealand system is not really touched by European arguments as to whether and to what extent 'quiet lanes' should be delineated or marked. UK 'quiet lanes' are defined as:

> *Quiet Lanes should generally be pleasant to walk, cycle, or ride a horse along. This would usually involve low traffic speeds (85th percentile <35 mph), low traffic flows (<1000 vehicles per day), and narrow road widths (<5 m*). (Department for Transport 2004)

Unlike in the UK where almost all roads are sealed, such roads where they exist in New Zealand would usually be unsealed and in rural areas[4] and thus would be limited to the use of warning signs or EMPs on isolated sections. For unsealed roads, Boschert et al (2008) provide a discussion of alternative safety measures. Also, if the guidance in the RTS 5 is followed, the only delineation that would be used on roads of width less than 5m would be EMPs.

3.6 Effects of particular delineation devices and markings

It is well established that disproportionately more crashes occur at night, suggesting visibility (or lack of visibility) is a factor. However, there is difficulty in assessing the contribution of individual components of any road delineation system, taking into account the extensive time often required for gathering crash

[4] Such roads would also be of lower volume in New Zealand as it would be rare for a road of 1,000 vehicles per day to be less than 5m wide or unsealed here.

statistics. Similarly, issues of degradation and reduction in retroreflectivity are frequently not accounted for as the system ages (Dravitzki 2005), which makes it difficult to assess relative performance.

Dravitzki (2005) proposes the focus should be on simpler and clearer delineation rather than more and brighter delineation. The following section examines different characteristics and types of delineation devices and how these influence safety and driver satisfaction.

3.6.1 Roadmarking materials

Typically, there are two types of traditional line marking materials; paint and long-life product (cold applied plastic and thermoplastic). Long-life product can be installed in several formats which sit prouder of the road surface than paint, thus aiding wet weather visibility. Both have been used widely in New Zealand, with variations dependent on cost, pavement surface, contract type and the requirements of the road controlling authority. There is often much disparity in the quality of the marking as this is influenced largely by marking system product selection, application equipment, operator skill, road surface and conditions at the time of installation (eg temperature). These factors can affect not only the life span of the product but also the retroreflectivity and the subsequent degradation of the markings. The life span of the product is also influenced by traffic volumes and type.

Newer roadmarking materials include wet weather paints, in which glass beads have been embedded and have enhanced retroreflectivity over paints without glass beads, particularly improving night and wet performance (eg 3M 2013; section 3.7). There are also ATP markings (or rumble strips, structured markings see section 3.6.9) and roadmarking tapes that adhere to the road (see section 3.7). A key property of roadmarkings that improves visibility and sight distance of the road ahead is retroreflectivity.

3.6.2 Retroreflectivity

In a rural driving context retroreflectivity is essentially the amount of light reflected back off a delineation device from car headlights. Research suggests that better retroreflectivity improves speed maintenance, lateral lane positioning and reduces perceived driving-related workload (Kalchbrenner 1989). However, Dravitzki et al (2006) found brighter roadmarkings did not always conclusively lead to improved safety. In fact, given the inconsistent retroreflectivity provided by the mixed system, brighter roadmarkings may distract the driver due to contrasts with other delineation (Avelar and Carlson 2013).

Avelar and Carlson (2013) recently attempted to understand the reasons behind mixed and often contradictory research around the relationship between retroreflectivity and night-time crash statistics. They utilised the Michigan State database of night-time crashes, retroreflectivity and road characteristics, finding an association between pavement markings and night-time safety. Of particular interest is the effect of high brightness contrast (between white and yellow markings) which seems to be associated with a reduction in night-time safety. They suggest that while the combined retroreflectivity of the white and yellow markings enhances safety, a large difference in retroreflectivity between the two reduces safety. While the underlying reasons behind this are unclear, it may be that as the difference between the two markings increases, the duller marking is less easily detected by the driver, reducing road navigation ability. However, this is just one possible interpretation.

European research on retroreflectivity recommends a minimum value of 150 mcd/m2/lux in dry and 35 mcd/m2/lux in wet conditions, with a minimum marking width of 150 mm (6”) (European Union Road Federation 2013) to provide adequate navigation and positioning information. New Zealand minimum retroreflectivity requirements are 100 mcd/m2/lux in daylight conditions with a minimum marking width of 100mm. High performance standards for roadmarkings in New Zealand recommend 150 mcd/m2/lux in dry and 80 mcd/m2/lux in wet, with 150mm width. Table 3.2 summarises these retroreflectivity numbers.

Dravitzki et al (2006) undertook an analysis of before-and-after data on selected New Zealand roads after the installation of brighter roadmarkings, finding no significant benefits. They suggest this research supports some degree of risk compensation; where drivers may adjust their behaviour to maintain a constant risk perception, most importantly by reducing speed. Confounding issues may have included the presence of other types of road delineation, crash reporting behaviour and a comparatively moderate improvement in marking brightness.

In a driving simulator study, Horberry et al (2006) found enhanced roadmarkings (higher retroreflectivity) in wet night-time conditions resulted in improvements in lateral positioning and target speed maintenance. An expert panel was used to make changes to overcome fidelity issues with simulation of the wet night-time conditions for the standard and enhanced markings. Actual retroreflectivity differences between the markings were not provided. Drivers were less likely to cross edge and centrelines with the enhanced markings, suggesting important implications for road safety. In another New Zealand study, Walton et al (2011) found that with an increase of retroreflectivity from 38 to 142 mcd/m2/lux (see figure 3.1), driver behaviour at night mimicked that of daytime conditions, indicating driver satisfaction was improved.

Table 3.2 Roadmarking retroreflectivity recommendations

General minimum recommended standards	Retroreflectivity (mcd/m2/lux)		Line width
	Dry conditions	Wet conditions	
New Zealand	100	–	100mm
New Zealand high performance markings (NZ Transport Agency P30 2009)	150	80	150mm
USA (depending on which state; Debaillon et al 2008)	100–130	–	-
Europe (European Union Road Federation 2013)	150	35	150mm

Figure 3.1 Example roadmarkings before (left 38 mcd/m2/lux) and after (right, 142 mcd/m2/lux) an upgrade

3.6.3 Edgelines and centrelines

Edgelines and centrelines have been shown to impact on both speed and lateral position, two factors which have an important influence on safety in rural areas. However, as with the impact of most forms of delineation, findings related to the impact of edgelines and centrelines on driving behaviours and safety have not always been consistent in the literature. Meta-analyses have therefore been completed in an effort to reduce some of the ambiguity in the literature. For example, Davidse et al (2004) conducted a meta-analysis of the impact of altered roadmarkings on the speed and lateral position of motor vehicles. Several kinds of alterations were studied, including applying an edgeline to a previously unmarked road or to a road that was already marked with a centreline. The results indicated the addition of an edgeline or a centreline to a road previously unmarked leads to an increase in speed and a shift of the lateral position towards the edge of the road. Crash studies were not included in this study, meaning the safety impact related to the observed changes is unknown.

Another meta-analysis by van Driel et al (2004) found the effect on speed of providing an edgeline was dependent on the presence or absence of a centreline. An edgeline without a centreline was related to an increase in speed, while the presence of a centreline without an edgeline was related to a decrease in speed. Other studies suggest crash rates decrease with the addition of both centre and edgelines independently (eg see Baas et al 2004 for a review), which might indicate that even if speeds increase, other considerations outweigh the increases in speed.

Dougald et al (2013) examined data in Virginia, USA and found the addition of an edgeline on low-volume, two-lane rural highways was related to a reduction in crash and fatality rates. It is important to note, however, that the results of this work were inconclusive overall and, in addition, likely largely dependent on other aspects of road design (eg shoulder and lane width). However, this finding is consistent with the assertions of Bass et al's (2004) review.

Tsyganov et al (2006) also investigated edgeline impacts on driver behaviour and reactions on roads. They found edgelines increased speeds on average by 5mph (or 9%) on both straight and curved highway segments with pre-existing centrelines, and moved vehicles towards the pavement edge in both daylight and darkness by an average of 20 inches. In addition, the presence of an edgeline reduced vehicle fluctuation around the centre of the trajectory by 20%, reduced driver mental workload, improved drivers' estimation of roadway curvature, and increased driver's advance time of intersection identification. A crash analysis carried out as part of this study indicated the net crash impact was positive, finding edgeline treatments on rural two-lane roadways might reduce crash frequency by up to 26%, which is in line with the findings of Bass et al (2004) and Dougald et al (2013). The highest safety impacts in Tsyganov et al's (2006) study occurred on curved segments of roadways with lane widths of 9 to 10ft (2.7–3m).

In contrast, a Louisiana study of rural two-lane highways (where the pavement width is less than 22ft) found after the implementation of edgelines, vehicles tended to move away from the pavement edge, increasing centreline crossings at several sites during daylight hours (Sun and Das 2012). This trend is therefore contradictory to findings of authors such as Tsyganov et al (2006), and also the findings of Davidse et al's (2004) meta-analysis, where lateral position appeared to be improved preceding the introduction of edgelines. However, in Sun and Das (2012), the presence of an edgeline did have significant benefits at night-time, when the distribution of a vehicle's lateral position was slimmed reducing the risk of head-on and sideswipe collisions. The impact on crashes was also estimated at an overall 17% reduction, therefore in line with the safety impact findings of previous authors (eg Bass et al 2004).

It has been suggested that when driving on particularly narrow rural roads without road-edge markings, drivers are likely to drift off the road, damaging the pavement edge and increasing crash likelihood (Steyvers and de Waard 2000). Steyvers and de Waard (2000) explored the safety impacts of the introduction of an edgeline on lower-category Dutch roads (under 5.0m wide) and found improved lateral lane positioning away from the edge (eg where travelling too close may result in damage to the pavement edge and possible crashes) and lower perceived mental effort (as found in Tsyganov et al's 2006 study). Vehicle speed also increased with the addition of edgemarking.

The addition of ATP markings to edge and centrelines is a relatively new treatment option. Agent et al (1999) suggest road safety is positively affected by centrelines and ATP markings, in descending order. As a general finding, centrelines are effective in separating opposing traffic, especially when visibility is low and on areas of horizontal curvature. The addition of ATP markings to centreline markings improves lane keeping and has a deterrent effect on centreline crossing (Olson et al 2011). Olson et al (2011) also recommended a system of record keeping be developed to better manage performance monitoring and accurately evaluate costs and benefits of different treatments, indicating further work in this area is required.

In terms of edgeline and centreline ATP markings, their positive impact on safety in terms of reducing runoff-road, head-on and sideswipe crashes is well attested (Neuman et al 2003). However, their impact on lateral position is less clear. Finley (2010) reported a field study to investigate the impact of side rumble strips (SRS) and centreline rumble strips (CRS) on vehicle lateral placement on two-lane, undivided roadways with various lane and shoulder widths. At CRS-only sites and sites with both CRS and SRS on narrow shoulders (1 to 3ft), drivers tended to position the centre of their vehicle closer to the centre of the travel lane than if the rumble strips were not present. In contrast, on roadways with larger shoulder widths (≥9ft) neither rumble strip scenario appeared to affect the lateral position of vehicles in the travel lane. The effect of SRS located within seven to nine inches of the edgeline on the lateral position of vehicles in the travel lane was highly variable. It seemed the effect of SRS close to the edgeline on vehicle lateral placement could be mitigated by including CRS.

Overall, the literature provides a relatively clear picture of the impact of centrelines and edgelines on safety, with all studies finding a positive correlation between their introduction and crash reductions. The effect of these forms of delineation on safety is likely due to their influence on lateral positioning, where in general this is improved after their introduction. Speed typically increased, but this relates to reduced mental workload and increased driver comfort. Most studies just report speed change and do not examine whether the speed increase is simply shifting towards comparable daytime speeds, indicating a driving environment comparable to daytime conditions. Inconsistencies in findings may be due to a number of factors, of particular note variation in road characteristics. Overall, it appears there is scope for further research on the impact of roadmarking delineation in New Zealand.

3.6.4 Audio tactile pavement markings

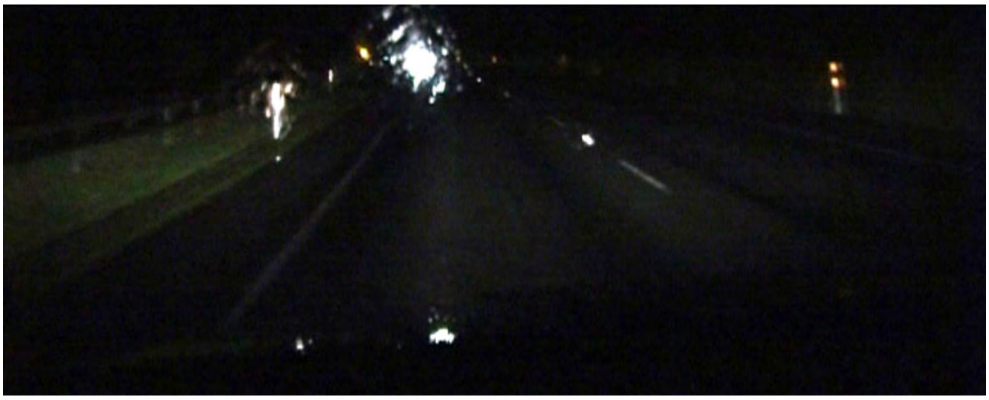
Research in New Zealand by Mackie and Baas (2007) supports previous research indicating ATP markings (of varying designs) are a cost-effective measure to enhance driver behaviour, in particular lane positioning (Olson et al 2013). Additionally, evidence suggests visibility of ATP markings in wet and rain conditions is enhanced due to the height above the road of the delineation (Agent 2013). KiwiRAP (2008) identifies ATP markings as one of the most effective road improvement tools available. A minimum shoulder width of 0.6m is recommended where edgeline ATP markings are installed to allow sufficient space for recovery after crossing the ATP marking (Georgia Institute of Technology School of Civil and Environmental Engineering 1997). The effect of ATP markings may be further enhanced, particularly on edges, by laying the ATP marking next to the edgeline, in effect widening the width of the marking.

However, Hatfield et al (2009) suggest much of the research into ATP markings is based on milled-in 'rumble strips' rather than the raised profile lane-markings, such as those used in Australia and New Zealand. They found while there is evidence to support the presence of edge and centreline rumble strips in combination reducing total crashes, either employed alone seems to have an inconclusive effect. They recommend where possible for both edge and centrelines to be treated with rumble strips.

Mackie and Bass (2007) developed a benefit-cost tool in New Zealand to analyse the effectiveness of ATP edge and 'no overtaking' centreline markings. They evaluated five sites in the mid-North Island, assessing driver lane positions, speeds and overtaking behaviour. This research suggests that even with modest daily vehicle traffic there are significant benefits to the installation of these types of road delineation and recommend widespread application.

As part of the South Waikato and Taupo Target (SWATT) 2010 monitoring project (Charlton 2006), 150mm ATP markings on the shoulder side of edgelines and 150mm on double yellow centreline were installed at four locations and raised domes at 1m centres (on standard 100mm centreline) were installed at a fifth location. Results indicated the ATP marking treatment produced a significant improvement in lane keeping at three of the four locations, beyond the improvements resulting from an increase in the width of the painted lines alone (Charlton 2006). Significant improvements in drivers' overall lateral displacement were also seen at two of the four locations (beyond that associated with increased line widths alone). It should be noted that a marked improvement in night-time delineation was noted at the four locations (see figure 3.2) although no retroreflectivity measures were taken. The raised centreline domes installed at one site produced a significant improvement in lane keeping in only one direction (one of the two lanes). A one-year post-treatment monitoring of crash data at the locations indicated a reduction in the number of fatal and serious crashes, reducing the annual social cost of crashes from $43 million to $12 million.

Figure 3.2 SWATT 2010 programme improvements in wet weather/night- time delineation following installation of 150mm ATP markings



Before treatment

After treatment

In a 2012 Transport Agency trial of 'wide centrelines' the centreline was replaced with two centrelines separated by 1.0m, as well as the introduction of ATP markings as shown in figure 3.3. The treatment was installed at four rural state highway locations. The results indicated a significant increase in the lateral separation between opposing vehicles (Burdett and Lilley 2012). There was no significant change in speed within or downstream of the trial sites as a result of the changed markings.

Figure 3.3 NZ Transport Agency trial of wide centrelines

Charlton (2007) found that centre and edgeline ATP markings (in addition to chevrons indicating corners) were effective in reducing driver speeds and improving lateral positioning. Although this study primarily assessed the merits of various curve advisory signs, it also identified ATP markings as a useful tool in eliciting change toward safer behaviour on roads with horizontal curvature.

3.6.5 Width of markings

Research surrounding installation of wider roadmarkings (from 100mm to 150mm) suggested significant crash reductions on two-lane rural highways (Carlson and Wagner 2012; Miles et al 2010). Both studies found increased width was more effective than increases in retroreflectivity beyond minimum threshold levels (100mcd/m2/lux). Further support of wider line markings is provided by a report commissioned for the Missouri Department of Transport (Potts et al 2011) which found significant reductions in crashes in an extensive six-year study. In terms of sight distance, Rumar and Marsh's (1998) review of roadmarking width indicates wider lines (such as an increase from 100 to 300mm) can allow drivers to detect markings by as much as 30% sooner. Wider lines appear to be particularly beneficial for intoxicated, young and older drivers (Gates and Hawkins 2002).

A trial of wider edgelines and centrelines in New Zealand was undertaken as part of the South Waikato and Taupo Target (SWATT) 2010 monitoring project (Charlton 2006). The SWATT 2010 project treated 114km of State Highway 1 between Piarere (between Cambridge and Tirau) and the Desert Road Summit. The standard 100mm painted edgelines and centrelines were increased to 150mm in width in stage two of this three-stage programme. The width of the lanes was decreased slightly as a result of this treatment (from an average of 3.5 to approximately 3.35m). The results indicated there was a statistically reliable improvement in drivers' lanekeeping (reduction in instances of drivers crossing the centreline and edgeline) at two of four treated locations monitored and an overall improvement in lane position (lateral position) at three of the locations. A slight increase in 85th percentile speeds was observed in one direction for one of the four locations treated. The line width treatment was followed up with installation of ATP markings on the edgelines and double yellow centrelines at three sites, and RRPMs on the centreline of one of the sites which resulted in a further improvement in lanekeeping and lane position (Charlton 2006).

3.6.6 Continuous roadmarkings

Continuous or solid markings provide better visibility than dashed or broken lines. Zwahlen (1987) found visibility was relative to the quantity of retroreflective material used in the markings. Consequently, continuous lines were detected significantly earlier than broken lines and wider lines enhanced this improvement. Rumar and Marsh (1998) reviewed a series of studies by Zwahlen, which identified that the detection of continuous roadmarkings was between 10 to 50% earlier (with factors such as width of lines improving detection distance). Solid lines typically also shift drivers away from the road edge (Rumar and Marsh 1998). Overall, this suggests continuous rather than point source (or intermittent) markings are preferable.

3.6.7 Amount of delineation

Baas et al (2004) found (in an extensive literature review) that drivers have a preference for increased delineation, particularly at night-time. This seems to be particularly the case for older drivers. Again, while driver satisfaction is a key success measure, it remains unclear whether this translates easily into a safer road network. Similar results were found by Carlson et al (2009), where drivers subjectively preferred wider, brighter and more delineation. Again, this was especially the case for older drivers at night.

3.6.8 Delineated lane width

Manipulations of lane width have been shown to have direct and long-lasting effects on drivers' speeds. An overall carriageway width of 6m was found to produce mean speeds of 80km/h and a width of 8m increased speed to 90–100km/h (van der Hoven 1997, cited in Charlton and Baas 2006b). At several locations in England the overall carriageway width was reduced by 33% to 3m (by creating a 1.5m non-motorised lane). The treatment resulted in significant 21% reductions in both mean and 85th percentile speeds (mean speed of 25mph, 85th percentile speed of 30mph) (Traffic Advisory Unit 2004, cited in Charlton and Baas 2006b). Similarly, an analysis of rural two-lane roads found a significant positive correlation between pavement width and speed even though the speed limit was the same on all roads (Martens et al 1997). One of the key findings in studies of the effects of road width is that the perceived width of the road is the important variable in determining drivers' speeds. Road narrowing has been found to reduce drivers' estimates of their driving speeds by as much as 11km/h (Elliott et al 2003, cited in Charlton and Baas 2006b).

3.6.9 Raised reflective pavement markers

A comprehensive review of RRPMs (Bahar et al 2004) found head-on crashes at night and in the wet were reduced by centreline RRPMs through a movement away from the centreline, and the benefit increased with traffic volume. Conversely, as road curvature increased, RRPMs had a negative effect on safety, perhaps caused by a movement towards the road edge (eg there is a curve angle threshold). RRPMs were effective in reducing wet weather crashes, particularly at night, most likely due to increased visibility. Overall on two-lane roadways, benefits in a reduction of night-time crashes were found when traffic volume was above approximately 15,000 vehicles per day. The study suggests RRPMs be used selectively only (eg based on curvature and volume characteristics).

Studies have shown drivers approaching a curve require three to five seconds preview distance to feel comfortable with changes in the road (Smiley et al 2004). During the hours of darkness it may be difficult to provide such long preview distances with paint marking. RRPMs in addition to road signs and chevrons have been effective in supplementing pavement markings.

In New Zealand, RRPMs are recommended on centrelines and no overtaking lines on rural roads with traffic volumes of over 1,000 vehicles per day (Transit NZ 1992). They are designed to be particularly effective in wet conditions; however, they are subject to deterioration due to impact and foreign material (eg a build-up of dirt on the surface of the RRPM (Ullman 1994)). The retroreflective properties of RRPMs can reduce markedly within a few months due to road film and surface abrasion, sometimes to as little as 1/20 to 1/50 of the original value, but remains relatively constant after this change (Migletz et al 1994). However, there is the suggestion that during wet weather the lens is covered with a water film and visibility is excellent, nearly a quarter to a third as good as the original value. New Zealand road controlling authorities see the short life of RRPMs as a particular issue on rural roads (Jackett 2006).

3.6.10 Edge marker posts

EMPs have a long history in New Zealand of providing long-distance navigational information. As stated above, the Tasman District Council (TDC) recently removed (or more accurately, did not replace) EMPs on portions of rural roads within their region. This change was associated with anecdotal driver dissatisfaction (eg Bashham 2012a; 2012b). However, as change is often not welcomed, it is not clear if the dissatisfaction was related to actual overall safety implications or if measures of driver comfort would be affected long term. Therefore, there is a need to investigate the influence of reduced reliance on EMPs on driver performance using measures beyond satisfaction.

EMPs are relatively new in Finland, introduced in the mid-1990s. Prior to their introduction, several trials were conducted to evaluate the effect on driver behaviour and crash rates. While drivers expressed satisfaction with the increased road delineation, perhaps due partly to ability to navigate the road at higher speeds, crash rates increased significantly on narrow, curvy and hilly roads with 80km/h speed limits (Kallberg 1993). The same was not the case on better standard 100km/h roads. This illustrates a possible trade-off between safety and driver satisfaction, represented by shorter travel times and increased comfort on narrow, low geometric standard roads.

A recent Nordic simulator study measured speed and acceleration under a variety of EMP conditions, ranging from none to standard Norwegian/Swedish edge marker spacing (50m apart), including the New Zealand standard of 100m on straight roads (Lundkvist 2013, personal communication). While better behaviour, measured by lower speed and less acceleration/deceleration, was found in conditions with EMPs on curves only and conditions without EMPs, driver satisfaction was reduced. Driver behaviour was not dependent, however, on the spacing of EMPs (100m or 50m apart). Consequently, in an effort to standardise amongst Nordic countries and to provide cost-effective delineation, there is an intention to reduce the standard spacing of EMPs in Sweden, in line with configurations in Denmark (spacing EMPs at 100m as opposed to 50m).

While simulator studies are widespread due to their cost effectiveness and ability to control external influences, validation and generalisation of results can only be carried out on actual roads. In real life, the reduction of speed in the no EMP condition was less than in the simulator, most likely due to the additional environmental cues not well replicated in the simulator. Further evidence of this was found by Rajamaki et al (2013) in a real-world trial on the effects of differing delineator post configurations (including no delineator posts). Speed and lateral positioning were only minimally affected by post configuration. Behaviour may be affected by driver familiarity in addition to the extra environmental cues not adequately mimicked in the simulator studies.

Schumann (2000) assessed the effect of EMPs on rural roads on steering behaviour through the use of an instrumented vehicle. He concluded tentatively from a very small participant set, that EMPs provide long-range guidance cues at night and enlarge the driver's field of attention away from the vehicle. EMPs may reduce the effort of steering and thus improve safety by enabling the driver to better monitor the environment. This research suggests that signalling changes in road geometry are a particularly important function of EMPs.

3.7 New materials

The key providers of new delineation materials in New Zealand were identified as Potters and 3M. Both were contacted about their products with a specific focus on an all-weather delineation solution (with particular concern for wet and rainy conditions).

Three potential candidate roadmarkings, using innovative new materials that had already been sufficiently tested to the point where they could be effectively applied in New Zealand conditions and meet with high performance recommendations for roadmarkings in New Zealand (NZ Transport Agency 2009), were identified. These three materials can be seen in table 3.3 with their respective retroreflectivity performance. Overseas locations are trialling similar new materials but there is typically a focus on monitoring performance based on durability, colour retention and retroreflectivity, as opposed to immediate driver behaviour effects or longer-term before-and-after crashes (eg Agent 2013).

Visibility in the rain is also difficult to measure due to the complexity of factors, such as diffusion of light from the rain under different conditions, rain on the windscreen and variation in window wiper quality or speed.

Table 3.3 Retroreflectivity in dry and wet for potential materials to trial

Material	Dry retroreflectivity (mcd/m²/lux)	Wet retroreflectivity (mcd/m²/lux)
Visimax DHR beads (Potters)	400	80–110
Waterborne paint elements (3M)	180	150
Stamark pavement tape technology 380AW (3M)	500	525

3.7.1 Visimax DHR beads

The Visimax DHR product uses large diameter, new glass beads, which use a thick film of paint and are already well established in Australia. The clarity of the new beads is typically higher than recycled beads. Figure 3.4 shows an example of the type of visibility improvement observed in wet night-time conditions. This material is similar to existing markings, but the points of difference include:

- thicker paint, approximately 330mm (compared with typical 180mm), meaning a higher profile which helps in wet conditions
- larger (about 1mm diameter), highly reflective glass beads
- the brightest dry night visibility of the paint-based markings
- specialised application equipment required for best results
- bright visibility in wet conditions, but visibility in the rain is not yet substantiated.

Figure 3.4 Examples of dry night (pictured left) and simulated wet night (pictured right) roadmarkings, with standard glass beads (the left roadmarking in both pictures) and wet- weather beads (using Visimax DHR beads; right roadmarking in both pictures). Source: Potters (2013)

3.7.2 Waterborne paint elements (3M)[5]

This all-weather marking is the best all-round performing paint-based marking. It provides a specialised product consisting of microcrystalline ceramic elements that are added to paint-based markings and enable a higher refractive index, meaning more light is reflected back in wet conditions (3M 2013).

The points of difference for elements are:

- mixed, specialised bead system with a mix of dry and wet reflective elements
- does not deliver a 'super-bright' in either condition (between 150–180 mcd/m^2/lux)
- brightest paint-based roadmarking for wet and rainy conditions.

3.7.3 Stamark tape (380AW)

Tape technology is rolled out and adheres to the road surface via its adhesive backing. Early tape technology was limited when compared with paint markings based on issues maintaining retroreflectivity over time, but improvements have overcome this barrier (Agent 1991). In a US trial in 1991, retroreflectivity values were consistently over 500 over a two-year trial period (using an earlier 1.75 grade pavement marking tape; Agent 1991). Another barrier is regions with regular snow, as their raised profile means damage from snow ploughs. US trials were conducted placing the tape in grooves in the road to overcome this (Agent 2013).

More recent long-life trials of Stamark tape (380AW) in Germany suggest it holds its values above 500 for three years, and holds above 150 for at least eight years (3M 2009). The points of difference for the Stamark tape are:

[5] Please note that at the time of publishing this report this material may have been superseded due to durability issues (as can be the case with innovative, new products).

- consistently higher retroreflectivity values in both dry and wet (500–525mcd/m^2/lux), and very reflective in the rain
- long-life retroreflectivity
- high initial material cost.

3.8 Consolidation of existing roadmarkings and delineation

Consolidation here refers to the reduction of the number of road delineation elements in the total system, replacing existing elements with elements that fulfil multiple purposes (ie are effective in a variety of conditions, including wet, dry, night and when raining). Consolidation of the existing delineation system may offer financial benefits without compromising success measures, such as safety.

ATP markings are an example of a marking that may not be used on low-traffic roads due to cost. However, their properties are such that if they were to replace multiple delineation materials they could be cost effective and maintain or improve safety. Agent (2013) reported in a literature review that ATP markings (compared with a standard painted line) provided better night-time visibility. In addition to the auditory and vibratory warning, they provided an extremely cost-effective solution to improving night and wet visibility (Kubas et al 2013). This may be attributed to the contour of the ATP markings providing better water drainage properties, in addition to the improved retroreflectivity from the raised profile.

Following this consolidation example, ATP markings could replace the wet weather function of RRPMs, the lane-keeping cues of traditional roadmarkings, with the added benefit of auditory and vibratory warning. However, there are a couple of barriers to overcome with consolidation, which would explain why consolidation trials are not more widespread. Similarly, FHWA's *Manual of uniform traffic control devices* recommends that if higher minimum retroreflectivity levels of roadmarkings (250 mcd/m^2/lux) can be achieved, then complementary delineation devices, such as RRPMs are not required (FHWA 2010).

3.8.1 Public expectations and consolidation (or reduction)

A limitation to testing the consolidation (or even any saturation effect) of existing delineation in real-world settings is a concern for safety and being able to evaluate changes safely. Historically, this is why there is a process of only adding delineation in real-world trials. But trialling differing delineation treatments, where existing elements are removed, is often limited to the use of driving simulators, where there is better experimental control and participating drivers are not at risk. It should be noted simulator versus road experiments can produce different results and simulator experiment findings do not always transfer well to on-road behaviour. A discussion on the validity of simulator results can be found in Rudin-Brown et al (2009).

Public backlash is another barrier to change. In 2010 the Tasman District Council decided to reduce road delineation and marking on low-volume roads. For example, reducing the use of EMPs and confining them primarily to areas of horizontal curvature and particular problem areas, as outlined in their road delineation policy (TDC 2010). Consequently, there was some public backlash and media attention to reduced marking, as the public believed there was good safety reasons for the delineation and were loss-averse (Basham 2012a; 2012b). The reduction in delineation still fell within the minimum standards for low-volume roads in New Zealand (Transit NZ 1992).

With limited road budgets, the argument put forth was that safety is compromised not by the managed reduction of road delineation, but in fact by unmanaged degradation or attrition, where drivers expect and trust a level of consistency and reliability that may not be met, for example due to failures and breakages through vandalism or crashes (TDC 2010).

3.9 Influencing factors to consider

3.9.1 Road geometry

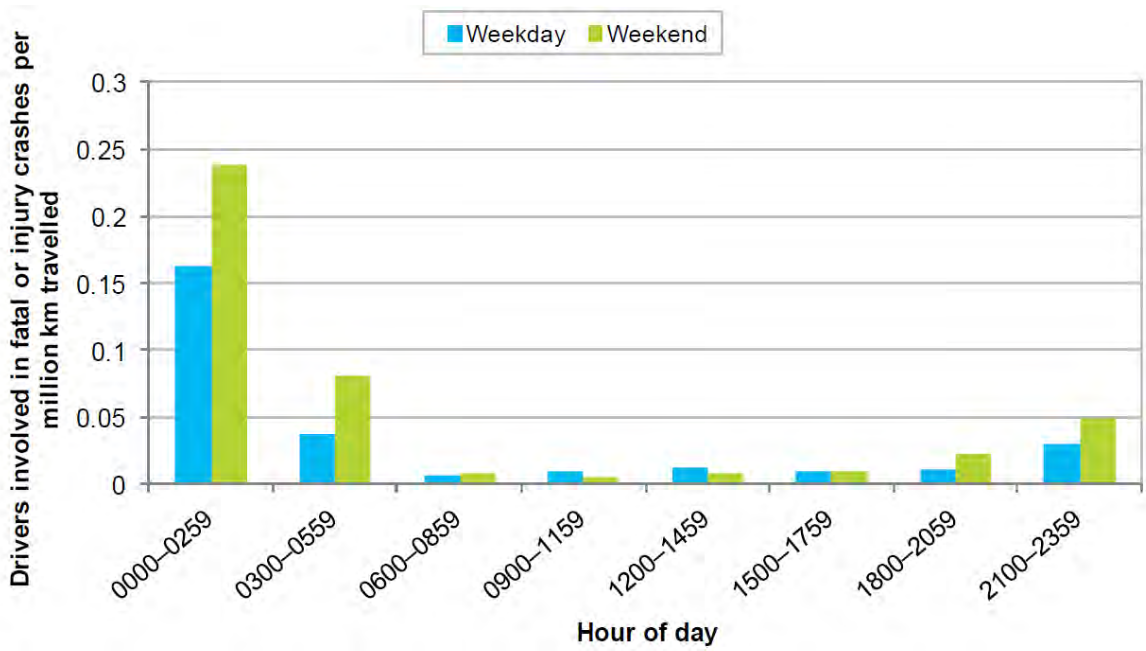
Crashes are more frequent and serious on curved sections of a road, particularly where more than one hazard is present (eg sharp horizontal curve and downhill grade). The leading location of crashes on open roads (where speed limit areas are over 70km/h) in New Zealand is at curves (44%), with 15% of all open road accidents occurring on curves during darkness (MoT 2012). Jamieson (2012) considered the use of wider clear zones or barriers to minimise 'run-off road' accidents. It is suggested a clear zone of 6m accommodates about 80% of encroachments but even at 9m there will be a proportion of vehicles that will exceed this. While road geometry and width is outside the scope of this report, it may be prudent to consider the road design when selecting the optimal delineation solution.

3.9.2 Night-time conditions

By their very nature, night-time conditions mean the visibility available for the guidance of drivers and to improve their ability to detect objects is reduced. A logical response to this situation has been to take measures, in the name of safety, to improve this visibility. These measures have included improving delineation and through-lighting measures (both on vehicles and on the street).

Not surprisingly, crash rates at night are higher than during the day. Figure 3.5 shows the variation of drivers involved in fatal and injury crashes per million kilometres travelled by time of day. It is apparent the greatest risks are after midnight, with weekends (where such problems as alcohol are at their peak) being the riskiest. It can be seen from the figure that, for instance, between midnight and 3am the risk of a driver being involved in a weekday fatal or injury crash is around 16 times higher compared with risk between 3pm and 6pm (where the weekday and weekend figures are very similar). For weekend crashes the multiple is around 24 times (compared with afternoon between 3pm and 6pm).

Figure 3.5 Drivers involved in fatal or injury crashes by time of day (Source MoT 2011)



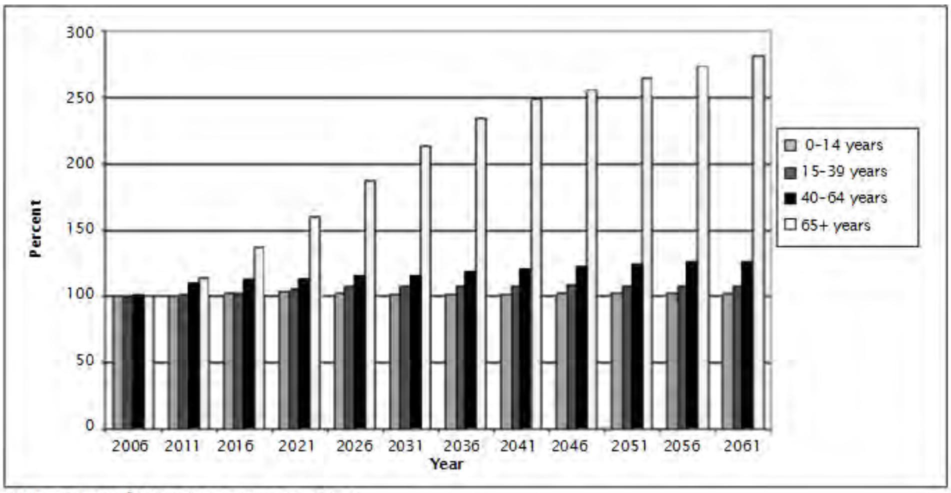
Thus, in New Zealand, night-time is a relatively dangerous time to be out on the road, particularly during the weekend. Safe system countermeasures to reduce this relatively high risk are therefore appropriate. The above figures are for New Zealand but a similar trend is found in all countries that report results. An example is the US, where according to Hassan and Lutkevich (2002) the night-time fatality rate is three times the day-time fatality rate.

The reasons for this greater personal risk go further than just the effect of darkness on the driver's ability to successfully navigate. There are other factors at play as well. These include alcohol consumption by drivers, fatigue and problems associated with circadian rhythms (for further information see MoT 2011). All these problems can be ameliorated to some extent by better delineation.

3.9.3 Driver age (vision vulnerable road users)

New Zealand is also beginning a substantial change in the visual acuity of the driving population associated with an increasingly ageing population. It is estimated that by 2031, one quarter of the population in New Zealand will be over 60 (see figure 3.6 from Frith et al 2012). While older drivers are less likely to drive in adverse conditions the impact of reduced mobility should perhaps be considered in addition to other road satisfaction measures. Even with reduced mobility, the percentage of driving by people over 65 years of age on New Zealand state highways is projected to double from 8% in 2006 to 16% in 2036 (see Frith et al 2012).

Figure 3.6 Projected change in age groups by year (base year 2006)



*Data courtesy of SNZ, using series 5 projections

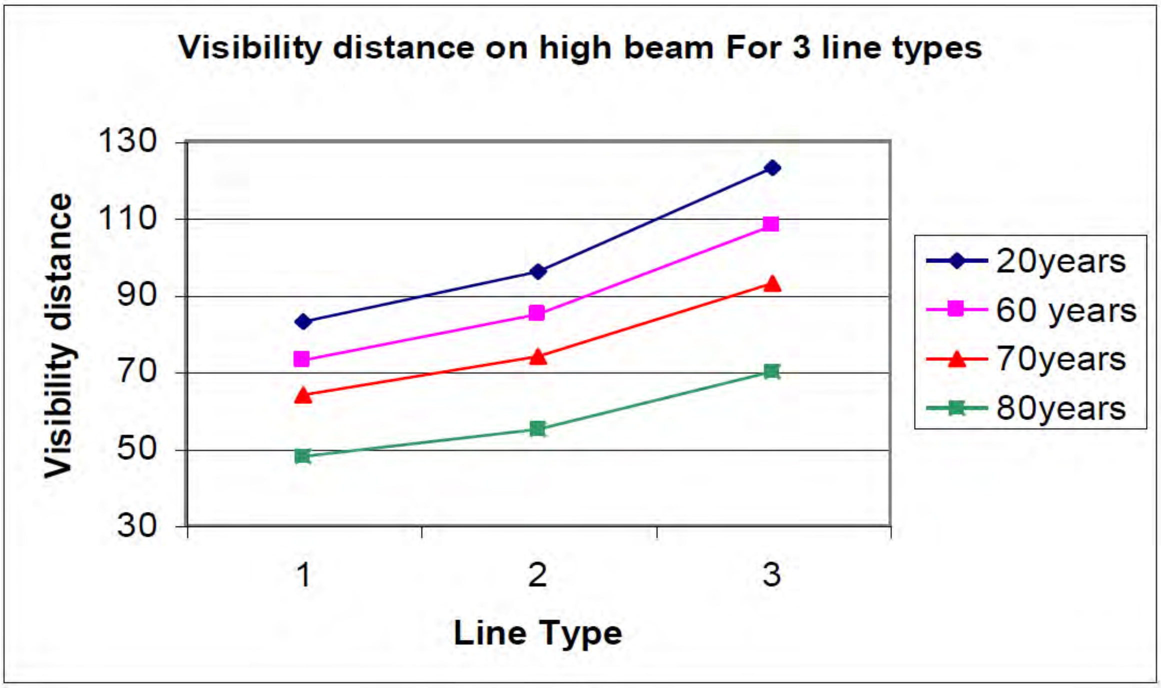
Older people have on average lower visual acuity than younger people and are also more susceptible to glare. CIE115 (2010, p5) goes into this in some detail and provides the following comparison of older people's vision with that of younger people:

> *Visual capability decreases with age. This occurs as the result of three effects. Firstly, the transmission of the ocular media decreases with age; for instance at the age of 70 it is only 28% of that of a 25 year old person. Secondly, light scattering in the ocular media increases with age, which reduces the apparent contrast of objects so that, for instance, for a 70 year old person there is on average 2.2 times more scattered light, expressed as the equivalent veiling luminance, than for a 25 year old person. As a result of these first two effects, a higher contrast threshold is required for the perception of targets by the older person. Thus, a 70 year old observer requires about three times more contrast at the threshold of visibility*

than a 25 year old observer. Thirdly, the receptor density in the retina decreases with age, thus reducing the ability of the eye to resolve detail even if the eye is optically corrected.

This results in older people needing to be closer to a given object in order to see it clearly, particularly at night. Thus, for edgelines for instance, for a given visibility distance older drivers require a wider line, or extra illumination in the form of lighting. This is illustrated in figure 3.7 from Dravitzki et al (2003), which shows the visibility distance under high beam for three line types (moderate, good and very good) and four age groups.

Figure 3.7 Visibility distance by driver age under full beam of two current moderate- to- good edgeline markings and a third very good marking (Source: Dravitzki et al 2003)



This means that guidance to night drivers either by delineation or lighting (or a combination of both) is likely to become more of an issue in the future with an ageing population. Other safety factors to consider within the general population are that drivers may be vulnerable because of impairments such as distraction, alcohol impairment or fatigue.

Therefore, it would be prudent to consider improving the visibility of objects like roadmarkings to take into account vulnerable road users, by improving the markings and delineation, improving lighting or both. As the cost of lighting makes it only economic where traffic volumes are relatively high, in most rural settings the solution will be delineation.

3.9.4 Wet conditions

In New Zealand, there are about 120 wet days (so about 33% of days) every year on average (with at least 1mm of rain).[6] The risk of crashing has been shown to increase in wet weather (eg Elvik et al 1997; SWOV 2012). In a meta-analysis examining the relationship between crash risk and wet weather, Qiu and Nixon (2008) found a 71% increase in crashes in wet conditions. Mental workload is increased under adverse

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[6] www.niwa.co.nz/education-and-training/schools/resources/climate/meanrain

weather conditions like rain (Hogema et al 2005). Clear delineation acts to decrease this mental workload (Hogema et al 2005) and therefore improves safety during wet conditions. This is especially the case for RRPMs and road markings with increased height (such as ATP markings), that sit above any pooled water. Beyond visibility, there is also reduced road tyre friction in wet weather conditions which leads to crashes, so it is difficult to separate the reduction in visibility, increase in workload and reduced friction in terms of determining the contribution of each to wet weather crashes.

3.10 Summary and key research questions

After closer examination of the literature, there were several key areas for trial interventions that could be tested in this study, including:

- improved solutions for particularly poor visibility conditions, with a focus on wet weather and when raining
- new materials, especially those that need evidence to have the confidence to improve uptake
- consolidation or removal of superfluous delineation, especially where certain delineation effects may from the use of multiple products may be replaceable with a single product
- gaps in knowledge around minimum delineation widths and spacing, so the amount and frequency of material is optimised.

Overall, there were several key knowledge gaps that could be addressed by trials examining the following research questions:

- How can we improve the effectiveness of delineation in wet/rainy conditions?
- Is there a saturation point with delineation in certain driving environments (where taking one element away does not have any noticeable effect on performance)?
- What is the minimum spacing for intermittent or point source delineation, such as broken lines or EMPs, to be effective?
- Do continuous markings provide a more effective visual source to improve lane negotiation than point source delineation (such as RRPMs)?

3.10.1 Road delineation trial options

Based on this review, a series of trial options are summarised in table 3.4. These were shortlisted to four options for the on-road trials.

Table 3.4 Road delineation trial options

Title and description	Rationale	Potential benefit
New technologies for wet weather Remove centreline RRPMs and replace with brighter road line marking that provides better performance in the wet (material to be selected from those listed in section 3.9)	RRPMs provide a point source (ie discontinuous) light designed to enhance visibility in wet and at night-time conditions. Under conditions where both RRPMs and traditional roadmarkings are used linemarkings alone could be trialled, using a retroreflective linemarking material that performs equally well under wet, rainy and night-time conditions.	Consolidation/reduction of two delineation types into one multi-purpose delineation type. Provide a continuous (as opposed to point source) wet weather delineation treatment to improve navigation under difficult driving conditions. **References:** Bahar et al (2004); FHWA (2010), Horberry et al (2006); Ullman (1994); Smiley et al (2004)

Title and description	Rationale	Potential benefit
Replace RRPMs with ATPs Replace RRPMs with ATP markings	The purpose of RRPMs is to provide enhanced visibility in wet and rainy conditions and at night. Can the same be achieved with ATPs?	As per trial option one above: Consolidation/reduction of two delineation types into one multi-purpose delineation type. Provide a continuous (as opposed to point source) wet weather delineation treatment to improve navigation under difficult driving conditions. **References:** Agent (2013); Kubas et al (2013); Mackie and Baas (2007).
Targeted use of EMPs Remove EMPs on straight portions of a road. Limit their use to horizontal/vertical curvature and hazards (eg culverts, bridges)	EMPs provide long range information of the road ahead. The benefits of EMPs may be of limited value on straight roads where there is limited curvature (horizontal or vertical).	Ability to restrict the use of EMPs to signal curvature changes or point to roadside hazards. Cost savings around materials and also due to ease of maintenance (eg reduced roadside mowing costs) **References:** Schumann (2000); Rajamaki et al (2013); Lundkvist (2013)
Replace EMPs with edgelines On roads that typically only require EMPs (due to limited road width)	Currently roads less than 5.5m wide are provided only with EMPs. The trial would provide edgelines to give continuous on-road (as opposed to side of road) delineation.	Investigate comparative driver behaviour and any changes in driver satisfaction. There is a potential for improved lane position and driver satisfaction with edgelines. To better understand any change in risk profile when vehicles pass by each other in the opposite direction on a narrow road. **Reference:** Baas et al (2004); Steyvers and de Waard (2010); Burdett and Nicholson (2010).
Wider roadmarking Trial an increase in the width of roadmarkings	Wider markings improve visibility and have been linked to improved driver performance.	Examine the lane-keeping benefit of a wider marking, particularly for visibly vulnerable road users (such as older drivers). **References:** Carlson and Wagner (2012); Charlton (2006); Gates and Hawkins (2002).
Changes in delineated lane width Trial a reduction in delineated lane width	Reductions in lane width, achieved through installation of Transport Agency wide centrelines or placement of edgelines, or as part of ATP installation (see second option above) are effective in decreasing speed and speed variability.	Reductions in speed variability between drivers can improve safety, and improve throughput when traffic is congested **Reference:** Charlton and Baas (2006b)
Targeted delineation spacing Examining whether there can be a larger spacing between intermittent delineation without a reduction in driver performance	Examining the spacing threshold at which EMPs, RRPMs, or dashed pavement markings are effective (ie looking at placing more distance between posts). This would extend previous research	Wider gaps between markings will reduce the cost of materials and potentially reduce labour costs. Need to ensure any cost reduction is not offset by reductions in safety or driver satisfaction.

Title and description	Rationale	Potential benefit
	that suggests EMPs shifting from 50m spacing to 100m spacing were found to have little impact on driver performance.	**References:** Debaillon et al 2008; Lundkvist (2013); Rumar and Marsh (1998).
Brightness contrast Examining the minimum brightness contrast between different sections of road	Newer brighter elements are installed on the same portion of road as duller devices. Could investigate bright vs standard and faded vs standard	Investigate the issues (performance/ satisfaction) of elements of the system with contrasting brightness. Particularly if the price at which people are willing to accept a loss is greater than what they will pay to make a gain. **Reference:** Avelar and Carlson (2013)

3.10.2 Process for selecting the final trial options

A panel of 11 experts (representing road engineering, road safety, network optimisation decision makers, transport psychology and materials specialists) were presented with the benefits and limitations of the eight options above during an interactive workshop session to reduce them to four final options by a process of voting. The four final options chosen were (see section 2.3 for more details):

1. Targeted EMPs (removed on the straight)
2. Structured edgeline roadmarkings
3. RRPMs beside traditional edgeline roadmarkings
4. Audio-tactile profiled edgeline roadmarkings.

Within the selection process consideration and discussion was given to:

- **Practicality:** To take into account the practicality around the cost of materials and applicability to the conditions on low-volume rural roads in New Zealand. For example, this led to a move towards a structured marking with high index beads being identified as the best new material solution (as opposed to tape). It also led to discussions around the reliability of some new devices (such as LED RRPMs).
- **Poor visibility environments:** Discussed exposure to poor visibility environments that relate to crash risk, particularly wet weather conditions, and avoidance by some road users. Discussed retroreflectivity and the benefits and limitations of different solutions.
- **Continuous delineation:** Whether continuous line markings provided a more effective visual source to improve lane negotiation than point source delineation (such as RRPMs).
- **Targeted delineation:** With reference to the benefit of self-explaining roads and being able to signal changes to the driver around the risk profile of the road. For example, the cost savings from the EMP removal were negligible (even taking into account reduced mowing costs), but there was benefit in testing 1) whether increasing delineation at higher risk locations could cause detectable changes in driver behaviour, and 2) whether there is a delineation saturation point (ie if elements of the delineation environment were taken away would there be any detectable difference in comfort or safety).

4 Trial one: targeted delineation results

4.1 Trial location and setup

The purpose of this trial was to test whether targeted delineation could intuitively assist the driver to identify and respond appropriately to a relative shift in risk, such as a shift from a straight section of road to a horizontal curve. To test this EMPs were removed on a straight. The site location is shown in figure 4.1.

A Metrocount device was placed at locations 1 and 3 to monitor vehicle speed and headway on the straight sections of road before and after the curve. At the main monitoring site (location 2), the TIRTL was placed immediately preceding the curve (see figure 4.2 and table 4.1) to monitor vehicle speed, headway and lane position. Scaffolding was placed inconspicuously among trees here for observers to monitor the hand positions of passing vehicles from an elevated position to help observe low hand positions. Observers also collected number plates of vehicles in order to send questionnaires to drivers who had used the road.

4.1.1 Site crash history

Between 2009 and 2013 there were six crashes at the site, one fatal, two leading to serious injury, one leading to minor injury and three with no recorded injuries. Four of these crashes took place during the day while the other two took place at night. Two of these crashes were categorised in CAS as miscellaneous trailer or load, two were categorised around turning, one was loss of control while cornering and the last one (the fatality) was loss of control on the straight.

4.1.2 Targeted EMP treatment condition

In the targeted EMP condition, EMPs were removed on the straight (locations 1 and 3) immediately before (see figure 4.1) and immediately after the curve. The other existing delineation in the form of RRPMs, edgeline markings and a centreline marking were still in place. No change was made to the EMPs at the curve (measurement location 2), so drivers had a relative change in delineation at the curve.

Figure 4.1 Site location and site conditions showing full EMP (left) and targeted EMP (right) EMP removal on the straight road

Full EMP: Straight road before intervention **with** EMPs, RRPMs, edgelines and centrelines

Targeted EMP: Straight road after intervention **without** EMPs, but with RRPMs, edgelines and centrelines

Figure 4.2 Site location, marked with three measurement locations, and blue lines indicating the targeted EMP treatment condition where EMPs were removed on straight roads only

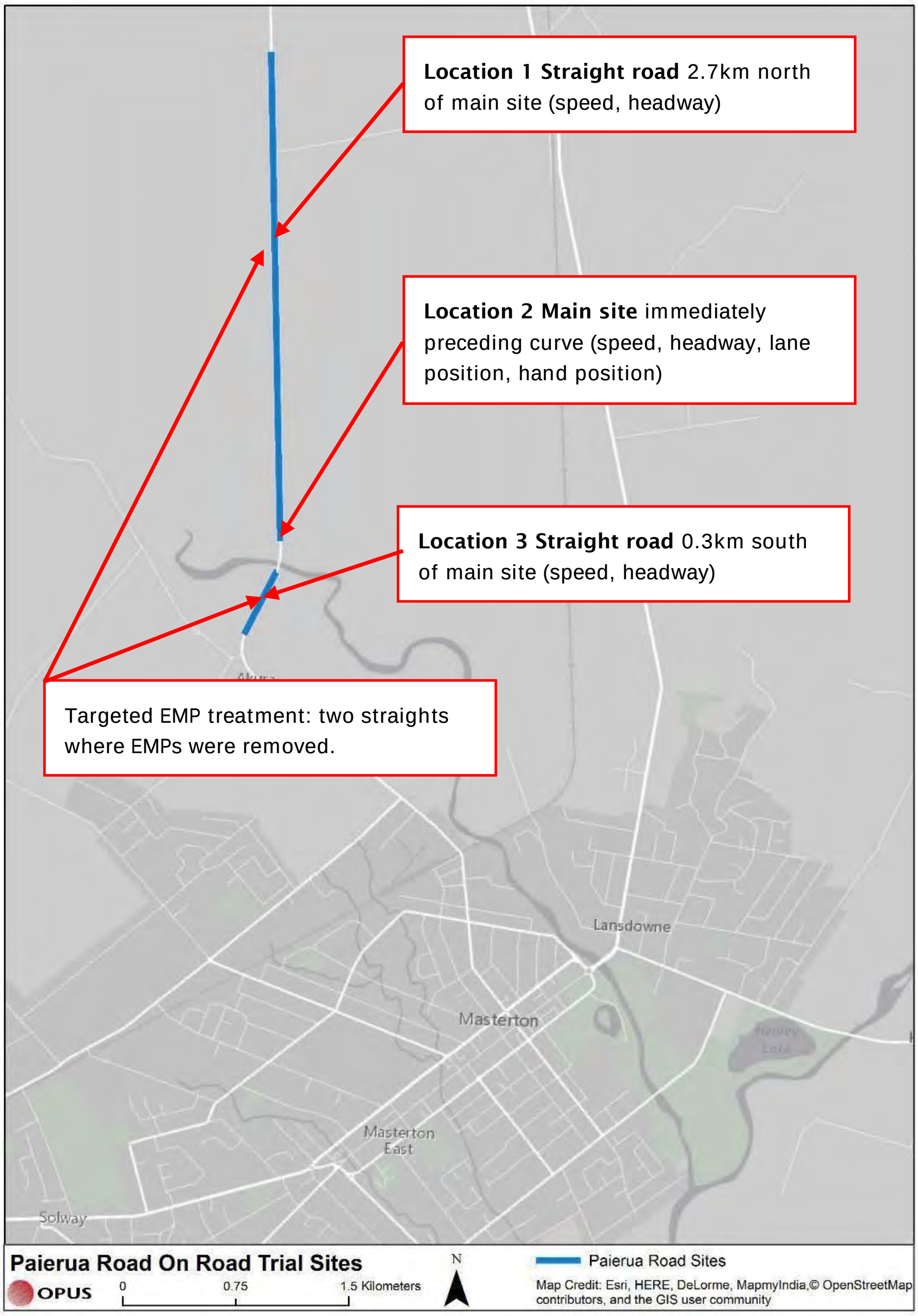


Table 4.1 Positional references for vehicle data capture equipment

Equipment	Easting	Northing	RP
Metrocount 1	1822443	5467488	PAIERAU ROAD/1.704
TIRTL	1822456	5466610	PAIERAU ROAD/0.837
Metrocount 2	1822347	5466244	PAIERAU ROAD/0.449

4.2 Observational findings

All vehicles travelling in a southbound direction were included in the analyses that follow. The rationale for this direction was to allow a reasonable length of straight road with the treatment condition, EMPs removed, prior to a curve to allow for the EMPs at the curve to be salient.

4.2.1 Hand positions

The only driver hand position finding that revealed a significant difference between conditions was between baseline day (full EMP condition) and treatment night (targeted EMP condition), so drivers were more likely to drive with two hands as opposed to one hand on the top half of the steering wheel in the targeted EMP treatment condition at night (χ^2 (1, n = 228) = 4.20, p < .05; see table 4.2). This could be interpreted in two ways: 1) It could indicate either greater discomfort when entering the curve (relative to full day, or ideal visibility conditions); 2) It could indicate higher perceived risk at the curve, so drivers are paying more attention at curves.

Table 4.2 Cross tabulation of hand positions at the curve (location 2) before and after targeted EMP treatment by daylight and night light conditions

Number of hands on top half of steering wheel		Full EMP daylight	Targeted EMP night	Frequency (n)
One hand	Observed count	95	42	137
	Expected count	87.7	49.3	137
	Adjusted residual	**2.0**	**- 2.0**	
Two hands	Observed count	51	40	91
	Expected count	58.3	32.7	91
	Adjusted residual	**- 2.0**	**2.0**	
Frequency (n)		146	82	553

Note: Adjusted residuals (AR) of 2 or more indicate a significant finding and are highlighted in bold. Positive AR values indicate greater than expected and negative AR values indicate lower than expected counts.

4.2.2 Speed, headway and lane position

4.2.2.1 Within location findings

Location 1: Straight section of road (2.5km before curve)

Independent samples t-tests found that the only significant difference in driver speed on the first straight section of road at location 1 was between day full EMP and night targeted EMP (t(224) = -1.96, p < .05; see table 4.3). This represented a small effect size, r= .13. There was also a significant increase in 85th percentile speed, with the night targeted EMP condition being significantly faster than all other conditions (see table 4.3). Finally, the frequency of non-compliance with the speed limit was significantly more likely in the night targeted EMP condition compared with the day full EMP condition (χ^2 (3, n = 666) = 10.57, p < .05).

Headway between following vehicles in the night full EMP condition appeared lower than all other conditions (however, the frequency of vehicles following within four-seconds of each other at night was too small to allow for statistical comparison; see table 4.3).

Table 4.3 Speeds and headways at location 1 straight section of road (2.5km prior to curve)

Metric		Day full EMP		Day targeted EMP	Night full EMP	Night targeted EMP	Significance
Speed (km/h)	Mean (SD)	93.54 (9.81)		94.08 (9.68)	93.83 (8.63)	95.90 (8.34)	*
	Median	95.00		94.80	94.70	95.80	
	85th percentile	99.74		102.80	100.12	103.60	*
	Non-compliance (% over 100km/h)	14.3 %		20.5 %	20.3 %	31.4 %	*
	n (vehicle count)	105		312	128	121	
Headway (seconds)	Mean (SD)	2.24 (0.96)		2.14 (0.85)	2.09 (0.66)	2.20 (0.69)	N/A
	Median	2.40		2.05	1.70	2.20	
	Failure to follow the 2-second guidance[a]	47.1% (4.8%)		38.5% (1.9%)	55.6% (0.8%)	38.5% (5.8%)	
	n (vehicle count)	17		26	9	13	

Note: * = p < .05; ** = p < .01; *** = p < .001. For failure to follow the two-second guidance, the percentage in brackets shows the proportion of vehicles (ie including non-following).

Location 2: Coming into curve

Drivers were travelling significantly faster in both night full EMP and night targeted EMP when compared with day full EMP, indicating speeds are typically faster at night (t (257) = -3.202, p < .01, representing a moderate effect size, r = .2; t (280) = -4.402, p< .001; also representing a moderate effect size, r = .25; respectively). Night targeted EMP did not differ significantly from night full EMP, nor did day targeted EMP differ from day full EMP, indicating speeds are typically faster as a consequence of a night profile rather than differences caused by the targeted EMP intervention (see table 4.4).

As with location 1, the 85th percentile speed was significantly higher in the night targeted EMP condition compared with day full EMP ($p < .05$), but there was no significant difference between night full EMP and night targeted EMP (or any other conditions, $p > .05$). Again, results failed to show any significant difference in the level of non-compliance across the four conditions for this location, χ^2 (3, n = 560) = 6.428, p = n.s.

Headway between following vehicles did not appear to show large differences based on the intervention (see table 4.4); however, the number of vehicles following within four-seconds of each other at night were too few to draw statistical comparisons. Headway during the day full EMP condition showed the greatest variation.

Lane position did not differ significantly between conditions (F(3, 556) = 1.287, p = .278, n.s.). There were no edgeline or centreline crossings for any vehicles in any condition. There was a tendency to keep closer to the centreline at night (but this was not a significant trend). This trend is also found in other studies, for example a recent lane position study in Auckland, New Zealand also found a shift towards the centreline at night, in motorway conditions on both straight and curved sections of road (Thomas et al 2013).

Table 4.4 Speeds, headways and lane positions at location 2 coming into curve

Metric		Day full EMP	Day targeted EMP	Night full EMP	Night targeted EMP	Significance
Speed (km/h)	Mean (SD)	89.40 (9.53)	91.40 (10.73)	93.10 (8.33)	94.38 (9.29)	***
	Median	91.00	92.00	93.00	95.00	
	85th percentile	98.00	100.00	101.00	102.10	*
	Non-compliance (% over 100km/h)	9.6%	13.6%	15.7%	20.0%	n.s.
	n (vehicle count)	157	176	102	125	
Headway (seconds)	Mean (SD)	2.32 (0.93)	2.17 (1.12)	2.33 (0.88)	2.24 (0.90)	N/A
	Median	2.00	2.00	2.00	2.00	
	Failure to follow the 2-second guidance [a]	31.4% (3.1%)	18.4% (5.5%)	16.7% (1.7%)	23.5% (2.7%)	
	n (vehicle count)	38	35	12	17	
Lane position (m from centreline to edge of vehicle)	Mean (SD)	1.00 (0.22)	1.01 (0.28)	0.94 (0.28)	0.92 (0.29)	n.s.
	Median	0.96	0.96	0.96	0.96	
	n (vehicle count)	176	157	102	125	

Note: * = p < .05; ** = p < .01; *** = p < .001. For failure to follow the two-second guidance, the percentage in brackets shows the proportion of vehicles (ie including non-following).

Location 3: Coming out of curve (on short straight)

Similar to location 1, there was a significant difference in mean speed as vehicles exited the curve at location 3, with drivers selecting higher speeds in the night targeted EMP condition compared with day full EMP ($t(237) = -2.716$, $p < .01$, representing a small effect size, $r = .18$). There was a significant increase in 85th percentile speed, with both targeted EMP conditions being significantly faster than the day full EMP condition (see table 4.5).

A significant difference was found in the levels of speed non-compliance across the four conditions for location 3 (χ^2 (3, n = 770) = 14.97, $p < 0.01$), with non-compliance being greater in night targeted EMP compared with the day full EMP. Such a result mirrors the mean speed finding at location 1, suggesting that changes in speed on straight sections of road were likely due to the removal of EMPs on straight roads (even short sections of straight roads).

The headway between following vehicles in the night targeted EMP condition appeared higher than all other conditions (however, the frequency of vehicles following within four-seconds of each other at night was too small to allow for statistical comparison; see table 4.5).

Table 4.5 Speeds and headways location 3: coming out of curve

Metric		Day full EMP	Day targeted EMP	Night full EMP	Night targeted EMP	Significance
Speed (km/h)	Mean (SD)	89.62 (7.27)	90.77 (9.32)	90.64 (8.71)	92.58 (9.29)	*
	Median	89.40	90.77	91.45	93.25	
	85th percentile	96.94	99.57	99.60	102.51	*
	Non-compliance (% over 100km/h)	6.4%	14.1%	11.4%	23.1%	*
	n (vehicle count)	110	390	140	130	
Headway (seconds)	Mean (SD)	2.02 (0.91)	2.21 (0.88)	2.10 (0.72)	2.26 (0.99)	N/A
	Median	2.00	2.05	2.05	2.15	
	Failure to follow the 2-second guidance[a]	48.1% (15.1%)	49.0% (3.1%)	40.0% (2.	35.7% (3.5%)	
	n (vehicle count)	49	27	10	14	

Note: * = p < .05; ** = p < .01; *** = p < .001. For failure to follow the two-second guidance, the percentage in brackets shows the proportion of all vehicles (ie including non-following).

4.2.2.2 Between location findings

In order to examine how drivers responded to changes in the road geometry, differences were examined *between* measurement locations 1, 2 and 3 in order to look at whether drivers showed greater adaptation to the curve in terms of speed or headway (see table 4.6 for overall differences).

Overall, average speed decreased from location 1 to location 2 and from location 2 to location 3 (see table 4.6). In the day conditions, drivers adapted by slowing down significantly from the straight when coming into the curve, but in night-time conditions drivers did not adapt (regardless of the EMP condition).

Table 4.6 Mean free speed comparisons across the three locations

Mean speed (SD) km/h				
Condition	**Location 1: pre- curve**	**Location 2: coming into curve**	**Location 3: coming out of curve**	**Significance**
Day full EMP	93.54 (9.81)	89.40 (9.53)	89.62 (7.27)	**
Day targeted EMP	94.08 (9.68)	91.40 (10.73)	90.77 (9.32)	***
Night full EMP	93.83 (8.63)	93.10 (8.33)	90.64 (8.71)	**
Night targeted EMP	94.08 (9.68)	91.40 (10.73)	90.77 (9.32)	*
Overall mean (SD)	93.54 (9.17)	91.81 (9.83)	90.61 (8.89)	***
n (vehicle count)	968	560	1,125	

No detectable headway differences were found between the three measurement locations for any of the four conditions for following vehicles, ie those following within four-seconds of the vehicle in front.

4.3 Survey findings

4.3.1 General ratings of rural roads in New Zealand

Survey participants were asked to rate the current quality of New Zealand rural roads. Of the responses recorded, 68.7% rated the quality of New Zealand rural roads as being good, very good or excellent (see table 4.7).

Table 4.7 Participants rating of New Zealand rural roads today (N = 67)

Current road quality	Frequency	Percentage
Poor	4	6.0%
Fair	17	25.4%
Good	32	47.8%
Very good	13	19.4%
Excellent	1	1.5%

When asked to compare the quality of New Zealand roads of today with the quality of rural New Zealand roads two years ago, approximately one quarter of respondents (28.4%) indicated they felt the quality of roads had improved (table 4.8). Further, it can be seen the majority of respondents (77.7%) felt the quality of rural roads had not deteriorated in the last two years.

Table 4.8 Participants rating of New Zealand rural roads two years ago (N = 67)

Quality two years ago	Frequency	Percentage
A lot worse	2	3.0%
A little worse	13	19.4%
No different	33	49.3%
A little better	17	25.4%
A lot better	2	3.0%

Participants were asked to rate various features of the New Zealand rural road network. Of the nine features included in the survey, more than 50% of the respondents rated six features as being ‘good or above’, as outlined in table 4.9. Road signs, management of environmental impacts and roadmarkings during daylight were the best features of the New Zealand rural road network. However, roadmarkings during wet conditions, the width of roads and lanes and the quality of the road surfaces were identified as requiring the most improvement.

Participants were asked to rate the overall quality of rural roadmarkings in optimal (daylight), night and wet conditions. Subsequent paired-samples t-tests revealed respondents perceived the roadmarkings as being of better quality in daylight conditions ($M = 3.07$, $SD = 0.83$) compared with at night ($M = 2.62$, $SD = 0.88$; $t(69) = 4.802$, $p < .001$). Similarly, the roadmarkings were perceived as being of better quality at night compared with in wet conditions ($M = 2.42$, $SD = 0.93$; $t(69) = 2.771$, $p < .01$).

Table 4.9 Ratings of features of New Zealand's rural road network (N = 66)

Features of rural roads		Mean[(a)]	Good/ very good/ excellent	Fair	Poor	Not sure
1	Road signs	3.15	78.8%	21.2%	-	-
2	Management of environmental impacts	3.14	69.7%	19.7%	4.5%	6.1%
3	Road markings during daylight	3.07	75.8%	22.7%	1.5%	-
4	Safety design and features	2.71	62.1%	30.3%	7.6%	-
5	Road markings during night time	2.62	53.0%	37.9%	9.1%	-
6	Construction and completion of rural road projects	2.58	57.5%	25.8%	16.7%	-
7	Road markings during wet conditions	2.42	46.9%	34.8%	18.2%	-
8	Width of road and lanes	2.33	43.9%	40.9%	15.2%	-
9	Quality of the surface	2.26	37.9%	43.9%	18.2%	-

(a) Mean ratings were also calculated for these Likert scale items, treating them as continuous variables.

Following analyses examining general road perceptions, the survey then probed into the participants' experience of driving through the trial area before and after the EMP treatment implementations. For this purpose, only those participants who indicated they drove in and around the Masterton area and also drove along Paierau Road (the bypass road), were asked subsequent questions.

After showing participants the trial location on a provided picture (see appendix A), and informing them when the trial took place, the participants were asked whether or not they had noticed EMPs were removed on the straight sections during the time of the trial. Results showed 66.1% of respondents who drove through the trial site failed to notice changes to the site, with a remaining 33.9% having noticed some changes (table 4.10).

Table 4.10 Respondents who drove through the trial site and whether they noticed any changes

	Frequency	Percentage
No, I did drive through, but did not notice any change to the site	37	66.1%
Yes, I did notice that something had changed but was not sure what it was	9	17.9%
Yes, I noticed that the edge marker posts had been removed	10	16.1%

Participants were then asked to evaluate how effective they perceived various delineation packages to be when driving on rural roads (from 1 = Poor to 5 = Excellent). Only the findings of participants who had driven through the trial site were examined. Table 4.11 presents descriptive results of participant responses for each measure, as well as the results of paired-samples t-tests.

Table 4.11 indicated that for all measures there was a preference toward the presence of full EMPs (on both straight and curved roads) by drivers who travelled through the site. It was expected that 'Ease of seeing upcoming changes in the road at night' might have improved in the targeted delineation post-treatment condition, but this also decreased. Also, the perception was that travel times would be slower, whereas objective data suggested improved travel times through faster speed. The findings could be indicative of a loss aversion bias.

Table 4.11 Mean scores and standard deviations for the full and targeted EMP conditions (for drivers who travelled through the site)

Measures		Full EMP baseline		Targeted EMP treatment		
		Mean	Standard deviation	Mean	Standard deviation	T value (significance)
1	Viewing distance of road ahead	3.37	0.96	2.78	0.95	4.527***
2	Estimating speed of oncoming vehicle	3.08	1.09	2.45	1.05	3.840***
3	Keeping you alert	3.17	0.89	2.61	0.92	4.231***
4	Ability to drive daytime speeds at night	3.00	0.87	2.41	0.99	4.646***
5	Comfort when driving at night	3.00	0.90	2.44	1.01	4.198***
6	Ease of driving for less experienced drivers	2.90	0.98	1.88	0.99	6.337***
7	Ability to keep a safe lane position	2.98	1.09	2.23	1.01	4.583***
8	Ability to safely follow another vehicle closely	3.17	0.91	2.54	0.97	4.258***
9	Comfort when driving in heavy rain	2.75	0.93	2.16	0.96	4.423***
10	Ease of seeing upcoming changes in the road at night	2.87	1.05	2.20	1.09	3.939***
11	Overall travel time on the road	3.20	0.93	2.73	0.95	4.195***
12	Overall safety	3.25	0.92	2.41	1.06	5.158***
13	Overall quality of the visual the driving environment	3.18	0.96	2.49	1.09	4.270***

Note: $p < .001$ = ***

Further findings indicated any loss aversion could be mitigated through a better understanding of where any cost savings might lead to other safety initiatives. While only about a quarter of participants agreed to the targeted use of EMPs in their region (26%), this increased to about a third of participants (36.6%) if the cost savings which resulted from these strategies were implemented back into the local road safety initiatives (table 4.12).

Table 4.12 Participants satisfaction with new delineation initiatives in their region

Satisfaction with	Mean score	Standard deviation
The removal of edge marker posts on straight sections of rural road in my region	2.55	1.22
Happy to have this introduced to my region if cost savings went back to local road safety initiatives	2.88	1.32

4.3.2 Driver willingness to travel in night and rain conditions

In order to further examine personal perspectives of road quality and its relationship to driving behaviours, respondents were also asked about their willingness to travel during the two poorer visibility conditions (ie night and in the rain) and, if willing, how much they would be willing to increase their travel time as a result of driving in these conditions. Specifically, respondents were asked whether they would prefer a slightly longer journey on a road that was ideal for the specified condition (eg high visibility and bright roadmarkings specifically designed for that condition) but also less direct, or would they prefer a slightly shorter journey on a dim road with poor visibility.

As can be seen from table 4.13, more than half the drivers collected in the sample indicated they were willing to travel during specified conditions after their experience with the EMP trial ($t(65) = 2.09$, $p < 0.05$).

Table 4.13 Driver willingness to travel in specified conditions

n=66	Willingness to travel for high visibility at night		Willingness to travel for high visibility in heavy rain	
	Frequency	Percentage	Frequency	Percentage
Yes, I am willing to travel in condition described, but would increase my travelling time	37	56.1 %	44	66.7 %
No, I prefer dimmer roads with short overall travel time	15	22.7 %	11	16.7 %
No, I will always travel the fastest road regardless of improvement	14	21.2 %	11	16.7 %

Furthermore, for those participants who indicated they preferred the longer journey, they were then asked to indicate how much time in minutes they were willing to add to their travel time – using a scale ranging from 0 to 5 minutes or more. Results showed such drivers indicated they were willing to add four minutes or more (which equates to almost 7km worth of distance) to their journeys in order to travel on roads better designed to these conditions (table 4.14). No significant difference was found in the amount of time drivers were willing to add to their journey between these conditions ($t(34) = -1.30$, $p = 0.20$).

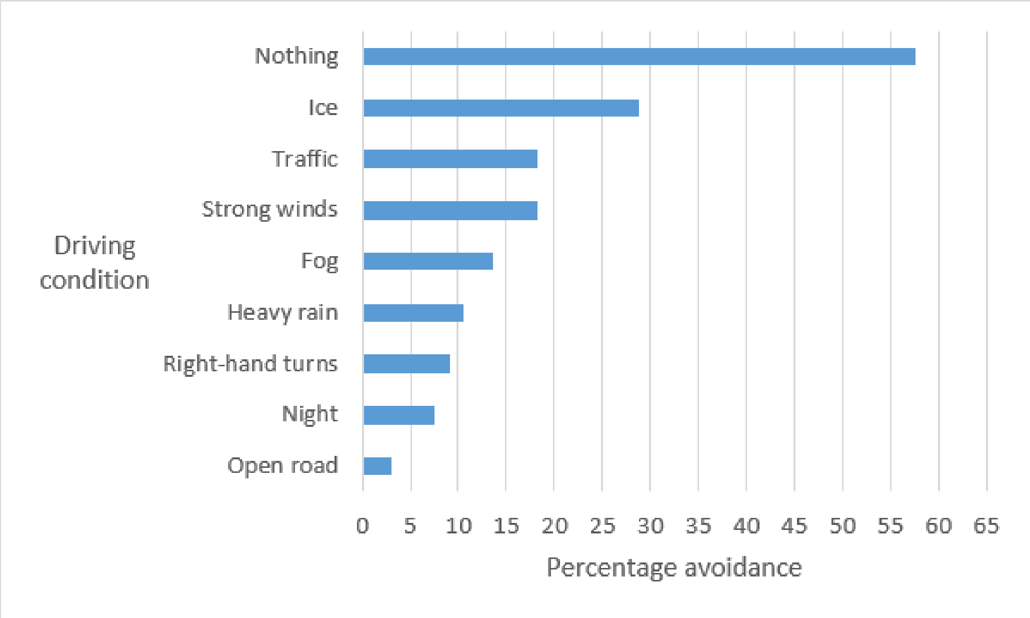
Table 4.14 Time willing to add to journey to travel in described conditions

Mean time willing to add to trip	Mean score	Standard deviation	Overall weighted average*	Percentage of trip duration increase (based on 25 min trip)
When travelling at night	4.26	1.25	2.39	9.56 %
When travelling in the wet	4.34	1.30	2.89	13.23 %

* Note: Including those who did not see the benefit of high visibility with 0 min willingness to travel scores.

While the majority of the sample indicated they were comfortable driving in most conditions, conditions most commonly avoided by drivers included ice, strong winds and higher levels of traffic (see figure 4.3 and appendix C).

Figure 4.3 Percentages of respondents who avoid driving in certain scenarios



4.3.3 Qualitative comments

In addition to the quantitative data, the survey included an open-ended space where participants were given the opportunity to provide written comments around their perceptions concerning the removal of EMPs on straight sections of road. The following section gives a summary of the themes that emerged from these comments.

First, about 69% (49 out of 71) of participants made comments relating to the delineation of the road environment. A few of the key themes were elaborated on, including poor environmental driving conditions, rural driving experience, the 'more is better' philosophy, trust in marking performance, and other pros and cons of EMPs.

There were many comments (n = 11) related to the need for better delineation in poor environmental conditions, particularly fog, but also driving at night in rain.

> *I am familiar with the road & know its general direction. The exception is rainy weather at night when visibility is poor.*

There were also four comments relating to the needs of more vulnerable users, particularly with concern novice drivers and drivers less familiar with New Zealand rural roads, including foreign drivers and New Zealanders with greater urban driving experience.

> *There are many inexperienced 'townies' that drive our rural roads, and I feel they need every assistance.*

There was an underlying philosophy raised by a few participants (n = 3) that relates to a belief that any increase in delineation equates to an increase in road safety. Such a philosophy most likely underpins much of the public reaction to any reduction in delineation on the road network.

> *The more markings, the safer the drive.*

> *Any lessening of road marking on <u>any</u> road is a backward step.*

There was a feeling that delineation could be used as a mechanism to offset the more difficult physical limitations typical of rural roads.

> *I feel rural roads are narrow, that's ok if you make [the] edge and middle of the road more visible.*

There were some positive comments about the removal of EMPs on straight sections of road (n = 5). However, this was only the case as long as other existing delineation was not only sufficient, but also well maintained. This may underpin a trust issue relating to any poor-performing delineation on rural roads. Retroreflectivity issues over time were raised with both line markings and RRPMs, where fading was observed to occur.

> *Agree with edge marker posts being removed on straights. As long as road markings were kept regularly maintained for clearer visibility at night.*

In terms of disadvantages of the removal of EMPs on straight sections, two participants also pointed out the use of EMPs to help as a distance cue on rural roads.

> *I think they still need to be used on the straights to enable you to measure distances.*

One participant felt that EMP removal on straight sections would be a positive, as EMPs interfered with the ability to pull over to the left in certain instances.

> *Removal of edge marker posts would make it easier to pull off to the left when I am wanting to make a right-hand turn into driveway (give way to traffic behind).*

5 Trials two, three and four: wet weather delineation results

5.1 Trial locations and setup

Trials two to four were conducted predominantly in wet weather at two separate locations: sites one and two, located 22km apart on SH57. This was done to study the effect various treatments had on wet weather driving. As with the EMP trial, scaffolding was used to elevate observers to assist seeing drivers' hand positions. While site one was conducive to erecting scaffolding in a manner that made driver observations covert, site two offered no such opportunity. Site one was located on Old West Road while site two was on Tennent Drive. Figures 5.1 and 5.2 show the location of the two trial sites where the Metrocount and driver hand position observations took place. Table 5.2 states the geographic coordinates of the Metrocount location.

The road surface at site one was last resealed in January 2007 with one chipseal using grade 3 aggregate. For site two the road surface was last resealed in February 2013 with a racked-in seal using grade 2/4 aggregate (a technique that has only really been adopted in the last 10–15 years).

5.1.1 Site crash history

There were no recorded crashes between 2009 and 2013 at site one. However, there were four crashes at site two, two leading to minor injuries and two with no recorded injuries. Two of the crashes were in the day, with one also in the wet. The other two crashes were at night in the dry. Three of these crashes were categorised in CAS as loss of control events while cornering and the other was categorised as loss of control on a straight road.

5.1.2 Treatment conditions

Three separate treatment conditions were tested over the two sites. One treatment condition was tested at site one while two separate treatments were tested at site two. Table 5.1 gives a complete breakdown of the treatment conditions by site.[7] Appendix D shows the edgeline treatments (the centreline was not altered during these trials).

Table 5.1 Detail of treatment conditions by site

Site	Treatment	Detail
1 (trial two)	Structured marking	300m white 100mm wide thermoplastic structured marking mixed with drop-on Potters Industries LLC ultra 1.9 high-index retroreflective glass spheres
2 (trial three)	Raised reflective pavement marker (RRPM)	16 red mono directional APEX Universal Inc Model 828. Applied at 20m gaps.
2 (trial four)	Audio tactile pavement (ATP) marking	300m white 100mm wide thermoplastic ATP at 250mm spacing mixed with drop-on Potters Industries LLC ultra 1.9 high-index retroreflective glass spheres. There were no RRPMs for this treatment (they were removed from this site after trial 3).

[7] Previous studies show that wider markings do improve visibility of the line. For the marking treatments (treatments 2 and 4), this was controlled to ensure the width was identical between baseline and treatment at 100mm, as the marking material type was the focus of the trial (even though industry standards may vary for some treatments, such as ATP markings).

Figure 5.1 Location of site one (marked in blue) on SH57 near Palmerston North

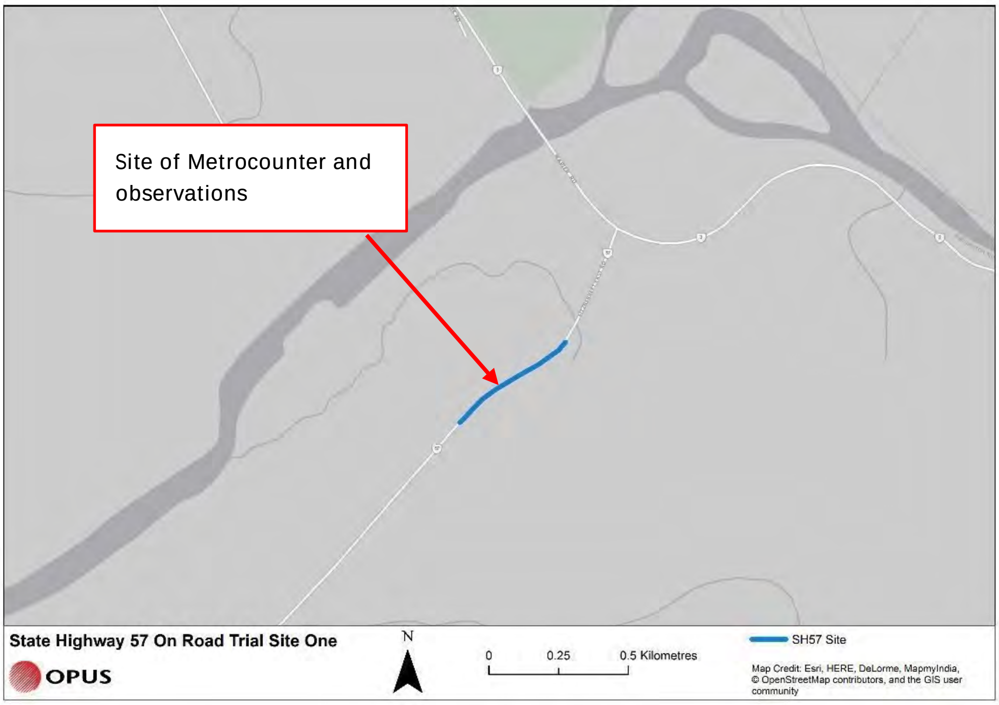


Figure 5.2 Location of site two (marked in blue) on SH57 near Palmerston North

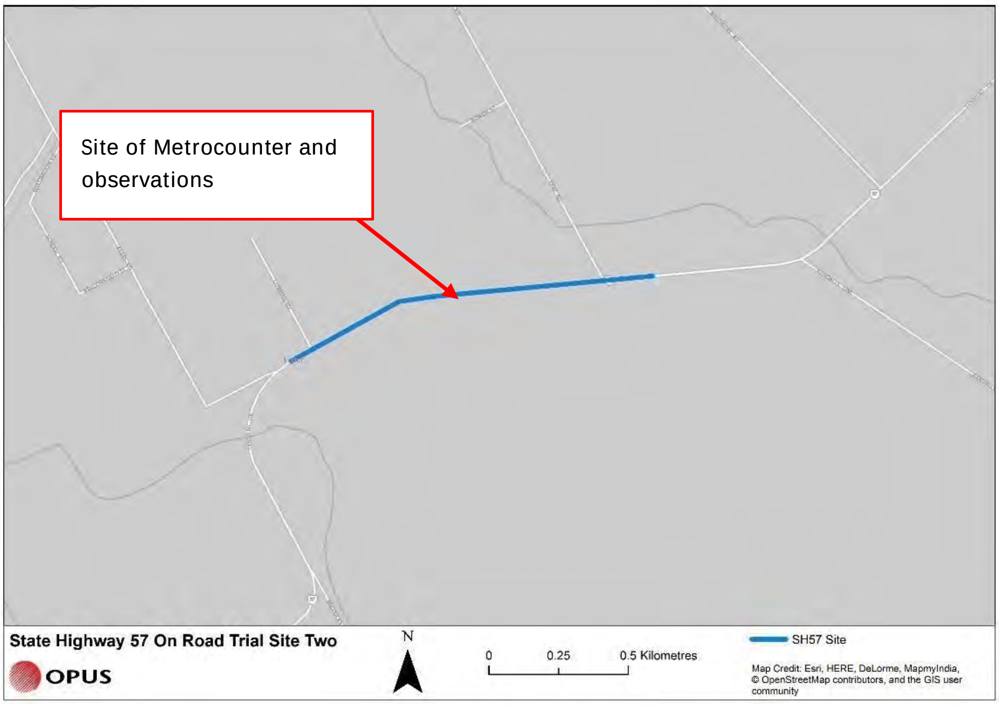


Table 5.2 Positional references for vehicle data capture equipment

Equipment	Easting	Northing	RP
Site one Metrocount	1834288	5533702	057-0050-B/13.980
Site two Metrocount	1817503	5521393	057-0036-B/5.484

5.1.3 Timeline of trials

Baseline measurements were taken at both sites on 24 March 2016. The first set of treatments was then installed at both sites and the second data collection took place on 18 May 2016. The final treatment was then applied at site two and the third and final data collection took place on 14 July 2016.

5.2 Observational findings

5.2.1 Hand positions

Hand positions were filtered to only include those observed in the rain. Rain in this instance was classified as any precipitation noted by observers irrespective of level.[8]

The analysis of drivers' hand positions indicated there were no significant differences between any of the treatment conditions compared with the baseline for either site. Also there were no significant differences in hand positions between treatment conditions when combining zero and one hand into a single group. The results of the chi-squared tests can be seen in table 5.3.

Table 5.3 Results of chi- squared tests for hand position vs treatment condition

Hand position	Trial condition	χ^2	df	p	significant
Zero vs one vs two hands	Site one baseline vs structured markings	1.636	2	.441	ns
	Site two baseline vs RRPMs	0.850	2	.654	ns
	Site two baseline vs ATP	1.347	2	.510	ns
	Site two RRPMs vs ATP	3.057	2	.270	ns
Zero and one vs two hands	Site one baseline vs structured markings	0.550	1	.458	ns
	Site two baseline vs RRPMs	0.570	1	.450	ns
	Site two baseline vs ATP	1.281	1	.258	ns
	Site two RRPMs vs ATP	2.922	1	.087	ns

5.2.2 Speed and headway

5.2.2.1 Site one findings (structured markings)

A series of independent sample t-tests were conducted to evaluate the effect of the structured marking treatment on driver speed. These tests only compared the speeds of drivers travelling towards the treatment, in moderate rainfall (between 2.1 and 6mm an hour), during the day and with vehicle headways of four seconds or greater (meaning vehicles were travelling at free speeds).[9]

The results indicated that drivers were significantly faster when the structured markings were in place (*M* = 89.15) than during the baseline period (*M* = 84.95), $t\,(251) = -3.54$, $p < .01$. This represents a medium effect size (r = .22). This significant increase in mean speed was accompanied by a significant increase in the 85th percentile speeds from 94.37 (SD 9.03) km/h for the baseline to 99.20 (SD 9.65) km/h for the

[8] Night-time hand position data was not collected due to issues around monitoring driver hand positions in the rain at night (eg rain causing reflection issues when using the IR lamps and night vision equipment).

[9] The data was too limited to perform any analyses for the wet night condition where rain conditions were comparable. Analyses examining the dry weather data revealed no significant differences between dry day and dry night in either the baseline or structured marking condition (with average speeds ranging between 89.7–90.2km/h).

structured markings, $p < .05$. Finally, the frequency of non-compliance with the speed limit was significantly more likely in the structured marking condition (χ^2 (1, n = 253) = 6.392, $p < .05$). Table 5.4 shows the descriptive speed and headway values for site one.

Table 5.4 Descriptive speed and headway values for site one baseline and structured markings

Metric		Site one (moderate rain)	
		Baseline	Structured markings
Speed (km/h)	Mean (SD)	84.95 (9.02)	89.15 ** (9.65)
	Median	84.44	89.33
	85th percentile	94.37	99.2 *
	Non-compliance (% over 100km/h)	4.7%	13.6%*
	n (vehicle count)	150	103
Headway (seconds)	Mean (SD)	2.08 (1.19)	2.21 (1.11)
	Median	2.05	2.2
	Not following 2-second guidance	47.37% (9.6%)	42.86% (7.3%)
	n (vehicle count)	38	21

Note: * = p < .05; ** = p < .01; *** = p < .001. For failure to follow the two-second guidance, the percentage in brackets shows the proportion of vehicles (ie including non-following).

To help determine whether the structured marking speed increase was a relatively safe speed increase, an analysis was conducted to compare day dry weather speeds (where there is arguably the best visibility environment) with day wet weather speeds. For the structured marking, if driver speed in rain was faster than baseline day dry conditions (where there is arguably the best visibility environment) it indicates an unsafe speed. However, there was no significant difference in driver speeds between dry (M = 89.73) and wet weather (M = 89.15) in the structured marking condition, $p > .05$. This means drivers were simply increasing speeds to those similar to day dry conditions, arguably based on a better visual driving environment that was as good as that seen in the dry condition.

Drivers were significantly faster in dry weather (M = 89.87) than wet (M = 84.95) in the baseline condition, $t(6706) = 6.30$, $p < .01$, which is a small effect size (r = .08). This indicates that without the structured marking, day wet speeds in baseline were not increased to speeds comparable to day dry speeds for baseline. Table 5.5 shows speed figures for site one for both conditions in dry and wet weather.

Table 5.5 Dry and wet speeds for baseline and structured marking conditions for site one

Metric		Baseline		Structured markings	
		Dry	Wet	Dry	Wet
Speed (km/h)	Mean (SD)	89.87 (9.47)	84.95 (9.02)	89.73 (9.40)	89.15 (9.65)
	n (vehicle count)	6,558	150	2,839	103

5.2.2.2 Site two (RRPM and ATP findings)

As with site one a series of independent sample t-tests were conducted to evaluate the effect of the two treatments on driver speed. Again these tests only compared the speeds of drivers travelling towards the treatment, in moderate rainfall (between 2.1 and 6mm an hour), during the day and vehicles with headways equal to or greater than four-seconds. The only exception to this was a comparison between RRPMs and ATP under wet night-time conditions (where there was enough moderate rainfall data).

Drivers were significantly faster when the RRPMs were in place (*M* = 93.99) compared to baseline (*M* = 88.37), $t(361) = -6.95$, $p < 0.01$, which represented a medium effect size (r = .34). There was no significant effect of the ATP on drivers speed (*M* = 89.02) when compared to the baseline (*M* = 88.37), $t(640) = -1.01$, $p > 0.05$. There was also a significant increase in drivers' speed when the RRPMs were in place (*M* = 93.99) compared with the ATP (*M* = 89.02), $t(589) = 7.07$, $p < 0.05$, which had a medium effect size (r = .28). In wet night-time conditions, there was a similar finding between RRPMs and ATP (which was the only wet night comparison that had enough speed data in comparable rain conditions). In the wet night-time condition drivers' speeds were therefore significantly faster when RRPMs were used (*M* = 94.95) compared with ATP (*M* = 89.45), $t(286) = 4.98$, $p < .001$, which had a medium effect size (r = .28).

Table 5.6 Descriptive speed and headway values for site two baseline vs RRPM vs ATP (wet day conditions)

Metric		Site two		
		Baseline	RRPM	ATP
Speed (km/h)	Mean (SD)	88.37 (7.71)	93.99 ** (7.51)	89.02 (7.54)
	Median	88.51	94.81	89.36
	85th percentile	96.18	101.19 **	96.36
	Non-compliance (% over 100km/h)	4.35%	21.80%***	6.90%
	n (vehicle count)	207	156	435
Headway (seconds)	Mean (SD)	1.86 (1.2)	1.87 (0.9)	2.24 (0.9)
	Median	2	1.8	2.2
	Not following 2-second guidance	49.37% (13.6%)	56.9% (16.7%)	39.07% (10.1%)
	n (vehicle count)	79	65	151

Note: * = p < .05; ** = p < .01; *** = p < .001.[a] For failure to follow the two-second guidance, the percentage in brackets shows the proportion of vehicles (ie including non-following).

Mirroring the increase in mean speeds, there were also corresponding significant increases in the 85th percentile speeds for the RRPM condition of 101.19 (SD 7.51) km/h compared with baseline of 96.18 (SD 7.71) km/h as well as compared with the ATP condition 85th percentile speed of 96.36 (SD 7.54) km/h, $p < .01$. However, there was no significant difference in the 85th percentile speed for the ATP condition 96.36 (SD 7.54) km/h compared with baseline 96.18 (SD 7.71) km/h, $p > .05$. Finally, the frequency of non-compliance with the speed limit was significantly more likely in the RRPM condition (χ^2 (2, n = 798) = 38.414, $p < .001$).

As with site one, drivers were significantly faster in dry weather (*M* = 94.78) than wet (*M* = 88.37) in the baseline condition at site two, $t(10148) = 12.22$, $p < .01$, which is a small effect size (r = .12). Drivers were not significantly faster in dry weather (*M* = 95.58) than wet (*M* = 93.99) in the RRPM condition, $t(4905) = 2.42$, $p > .05$. Finally, drivers were significantly faster in dry weather (*M* = 92.58) than wet (*M* = 89.02) in the ATP condition, $t(7506) = 9.52$, $p < .01$, which is a small effect size (r = .11). Table 5.7 shows speed figures for site two for all three conditions in dry and wet weather.

Table 5.7 Dry and wet speeds for baseline, RRPMs and ATP conditions for site two (day conditions)

Metric		Baseline		RRPM		ATP	
		Dry	Wet	Dry	Wet	Dry	Wet
Speed (km/h)	Mean (SD)	94.78 (7.46)	88.37 (7.71)	95.58 (8.14)	93.99 (7.51)	92.58 (7.59)	89.02 (7.54)
	n (vehicle count)	9943	207	4751	156	7073	435

It was postulated that the reason for there being no significant differences in driver speed between the ATP and baseline condition in the rain was that the road surface at site two was particularly conducive to effective roadmarking and water shedding. As seen in appendix D, site two had a coarse and textured mixture of grade 2 and 4 aggregate which was just over three years old meaning the surface would hold paint (and beads) and drained water more effectively than a worn-down road surface such as site one.

The above average effectiveness of the baseline marking at site two in the rain is supported by the fact that in dry conditions during the day drivers were significantly faster in the baseline condition ($M = 94.78$) than when the ATP treatment was in place ($M = 92.58$), $t(17014) = 18.78$, $p < 0.01$, which represented a small effect size (r = .14). Drivers were also significantly faster at night ($M = 95.83$) in the baseline condition than when the ATP treatment was in place ($M = 94.31$), $t(4615) = 6.09$, $p < 0.01$, which represented a small effect size (r = .09).

5.3 Retroreflectivity findings

An average of 14 retroreflective readings were taking during the baseline data collection period (at both sites) and for the structured markings at site one in wet conditions. No readings were taking for the RRPM (which should have a standard reflective profile).[10]

Table 5.8 Wet retroreflectometer readings for both baseline sites and the structured and ATP markings

Measure	Site one baseline	Site one structured markings	Site two baseline	Site two ATP
Average wet reading retro reflection (RL)	45.8	52.3	125.54	209
Average wet reading luminance (Qd)	211.7	188.4	127.13	143.6

Overall, these findings suggest some incongruence between physical performance measures like retroreflectivity and driver behaviour. In terms of retroreflectivity, the ATP marking performs the best in the wet and the structured marking does not show great improvement above baseline. However, the structured marking produced a significant behaviour change with faster speeds even though the retroreflectivity value had a minor increase. Also, the ATP marking had no noticeable behaviour change despite a big change in retroreflectivity.

[10] The specification for the RRPMs used in the trial can be found at the following address: www.apexmarker.com/pdf/specifications/SPEC-828.pdf

6 Discussion of benefits and costs

The benefits and costs associated with these changes in delineation are associated with safety, road user comfort, travel time and the physical costs of the delineation devices used. This section looks at the light which can be cast upon these costs and benefits by the results of this study.

The reader must bear in mind these are results from two specific stretches of road in the rural New Zealand road network. Thus any numbers that emerge must be treated as illustrative only. The discussion will draw upon the results of the four trials carried out. As can be seen from photographs and site details in other parts of this document the rural roads involved were of a relatively high standard. Consequently, the results of this work can be applied, although only illustratively, to the parts of New Zealand's rural road network classified as straight or curved, excluding those classified as winding or mountainous by the One Network Road Classification.

6.1 The removal of edge marker posts on a straight section of road leading up to a curve (trial one)

6.1.1 Edge marker post use and driver speed selection

EMPs are put in place as an aid for driver guidance, both for short distance and longer distance guidance. Internationally, they are placed beside different types of road at different gaps and different distances from the roadside depending on the jurisdiction that places them. Their size and area and brightness of their reflectorised material is also variable. Therefore it is not surprising that in the small amount of international literature relating to their impact on speed, variable results have come about.

There is, however, human factors literature (eg Fildes and Lee 1993) which suggests that roadside guidance (of which marker posts are a form) may assist drivers in moderating their progress along a road. This moderating of progress includes tracking their speed. Therefore, it is not altogether surprising that in this case on the straight section of road before the curve, night speeds increased significantly following the removal of guide posts, while day speeds showed no evidence of a change. This is because without the guideposts drivers may have more difficulty tracking their speeds at night than before.

6.1.2 Speed-related safety disbenefits of removing posts

This speed increase is likely to have a safety decrement associated with it notwithstanding the fact that drivers are unlikely to feel any difference. This is because there will be a relatively small increase in risk at an individual level, which would only become noticeable if such changes were made, with similar impact, over larger parts of the road network. The impact of such changes is best estimated using a formula discussed in Cameron and Elvik (2008). This formula was not derived for use with night crashes, but it is the best available way of making such an estimate. Use of this formula implies an increase in the social cost of crashes on straight road stretches associated with the removal of the post mounted delineators. This should be specific to night crashes as there was no change in daytime speeds of any practical importance between the two conditions. This is not surprising as the EMPs are aimed at night-time drivers.

The night-time mean speeds were 93.83km/h and 95.90km/h, a difference of 2.07km/h. According to Cameron and Elvik (2008), crashes on rural highways increase with speed to the power of 3.54. Applying this to our situation an injury crash increase of $(95.9/93.83)^{3.54}$ or 8% would be expected at night on straight road segments. There were 5,835 such injury crashes on the parts of the rural network studied during the project.[11] The social cost of an average rural injury crash is $539,000 (MoT 2016). Therefore, the total social cost over the study period of the 5,839 crashes is $3.1 billion. Were that to increase by 8% this would be an increase of $252 million over the five-year period, or $50.4 million per year.

6.1.3 Travel time benefits of removing posts

Roads are classified in the categories ‘straight’, ‘curved’, ‘winding’ and ‘tortuous’ in the One Network Road Classification. Were speed to increase and be replicated over the entire rural ‘straight’ road network of 26,680km[12, 13] then the total vehicle travel time would decrease. The straight network has 14,651 million vehicle kilometres of travel each year. Assuming 20% of this travel is at night we are left with 2,939 million kilometres of night travel per year. Using the night before average speed value of 93.83km/h, this number of vehicle kilometres is calculated to take 2,939 million/93.85 vehicle hours or 31.2 million hours. Applying these calculations to our situation, total annual travel time would decrease from 31.3 million to 29.5 hours, or in total 800,000 hours.

A July 2015 hourly value of travel time may be accessed by using a 2002 *Economic evaluation manual* (EEM) value of $22.72/hr (EEM table 3.7 for rural roads, not strategic, adjusted by the EEM prescribed factor ((EEM table A12.2)) of 1.44). This gives a figure of $32.7 per person hour. Assuming a vehicle occupancy figure of 1.7 (from EEM table A2.4 ‘Rural strategic and rural other roads/all periods’), this results in a total benefit in time savings of $44.5 million. This is 88% of the road safety disbenefits.

6.1.4 Annual infrastructure savings from removing posts

The total cost of buying and installing a marker post is approximately $46, and on straight stretches of highway they are spaced every 100m over 26,680km on each side of the road. Motorways comprise around 180km. This therefore corrects to around 26,500km. With marker posts placed at 100m intervals on both sides of the road, this means around 20 marker posts per kilometre, or in total 530,000 marker posts. At $46 each would these posts would cost $24.4 million. If an attrition rate of 10% a year is assumed, that is a recurring cost of $2.4 million per year. This assessment focuses on the maintenance cost of posts due to attrition, rather than the original purchase cost of posts.

6.1.5 Comfort and willingness to travel for high visibility road environments

Table 6.1 depicts the extra time drivers when questioned say they would be prepared to add to a 25-minute journey on an undelineated road in order to travel on a delineated road.

Table 6.1 Time willing to add to journey to travel in described conditions

Mean time willing to add to trip	Mean score (mins)	Standard deviation (mins)	Overall weighted average* (mins)	Percentage trip increase (based on 25- minute trip)
When travelling at night	4.26	1.25	2.39	9.56

[11] The crashes extracted exclude motorways, intersections, unsealed roads, crashes on bridges and crashes at railway crossings.

[12] Information provided by the Transport Agency.

[13] This figure includes motorways where the crash figures do not. Thus the crash figures will be more conservative than the time figures.

Table 6.1 indicates that when drivers have a travel time of 25 minutes they will increase it by around 10% at night and 13% at night in the wet to substitute an undelineated road for one that is well delineated. Their motivation is presumably some amalgam of safety and comfort.

These findings may then be applied to straight roads with and without delineation, making the assumption that such a percentage applies to all rural night travel, and assuming night travel on rural roads is around 30 million hours. Using these assumptions, a 10% increase in this travel amounts to an increase of 3 million hours corresponding to about $98 million per annum in social costs.

6.1.6 Summary of annual network benefits related to costs

Taking an overview, the cost and benefits of having post-mounted delineators on straight stretches of road may be summarised thus:

- crash-related safety benefits: around $50 million (measured by the crash disbenefits of not having the delineators)
- comfort and perceived safety benefits: around $98 million (measured by the percentage increase in travel time drivers will tolerate to travel by a delineated route)
- travel time disbenefits: around $45 million (measured by the decrease in travel time when the markers are removed)
- cost of the markers per year $2.4 million

Thus on a simple annual basis the quantified benefits are around $148 million, the disbenefits are around $47 million and the indicative benefit to cost ratio of the EMPs on the straight stretches of road is given by the quotient, 148/47, or about a 3 to 1 ratio. While this is indicative only (as it is in part based on comfort findings from a small sample of driver surveys), the important point here is that when factors like driver comfort are taken into account it shows the positive outcome of improved delineation devices, like the use of EMPs on straight sections of road.

6.2 Wet weather delineation at curves (trials two, three and four)

World-wide, targeted delineation at curves, sometimes using enhancements to the types of delineation used on straight sections of road is considered best road safety practice[14]. Unlike straight sections where the delineation arguably tends to reduce speeds by giving drivers a better idea of the speed they are travelling at, delineation at curves may result in faster speeds around the curve, as the driver may better know where they are on the road, and this greater sense of security may allow faster speeds to be achieved. This is fine as long as the design of the curve is such that inappropriate speeds are not encouraged. Also, mercifully, as time goes by it will be less likely that inappropriate speeds will happen as stability control (with its impact on cornering speeds), and other driver assistance systems that improve feedback on appropriate speed and lane keeping, become more entrenched in the vehicle fleet.

As described in section 7.2 three separate treatment conditions were trialled in this project.

- structured markings

[14] http://toolkit.irap.org/default.asp?page=treatment&id=5 Viewed 5/9/2016

- raised reflective pavement markers (RRPMs)
- audiotactile pavement markings (ATP).

The trials were purely related to the daytime wet condition (with the exception of a comparison between RRPMs and ATP). For wet night-time conditions the trial provided an indication that the experience of drivers may be enhanced at night, but this would need confirmation from possible subsequent work. All these markings were expected to have the ability to better delineate the curves at night and in wet conditions. The wet conditions effectiveness was expected to come from the higher profile of the markings making them shed water enough to be visible in the wet and also from the reflective properties of the delineation.

The trials found no change in driver hand positions for any of the treatments vis-à-vis baseline indicating no evidence of a change in driver 'comfort'. An upward change in speed was found with both structured marking and RRPMs. However, these were no greater than baseline daytime dry conditions, leading to a conclusion that the increased delineation had allowed drivers enough extra information to drive closer to dry weather speeds without feeling less comfortable, and arguably without being less safe. There are limitations here, for example this only takes into account visibility of the road to provide navigation cues, as opposed to hazard detection of objects on the road under wet night-time conditions (such as animals, debris or slips) [15], or ability to stop in wet conditions due to reduced friction. No such changes were found for ATP markings.

In terms of benefits and costs, if one assumes safety is not compromised, these come down to the costs of enhanced markings and the time saving benefits of the increased speeds around the curves in the wet. This experiment was not conducted on excessively sharp curves, so the part of the network to which it best applies would be that described in the One Network Road Classification as 'curved'.

Assuming all road segments classified as curved in the One Network Road Classification would qualify for the enhanced markings then the enhanced markings would be used on the entire length which is 3,683.5km. As the study showed no change for ATPs this discussion looks at RRPMs and structured markings only.

To estimate the time savings one requires estimates of the amount of driving in the wet. This is because the time savings shown in the trials only apply in wet conditions. A reasonable estimate of the number of rainy days in New Zealand is 120 based on an average of NIWA figures for all regions in New Zealand.[16] The NIWA figures are based on more than 1mm of rain per day. Therefore, it can be estimated that about 120/365, or around a third, of driving will be on rainy days. Then a range of arbitrary scenarios can be employed to further account for the actual amount of rainy day driving taking place in the wet. Those scenarios chosen are from 20% of rainy day driving in the wet through to 60% in the wet.

The time savings are estimated through the average percent increase in speed under wet conditions using the structured markings and the RRPMs. This is (89.15–84.95/84.95) x 100 for structured markings and (93.99–88.37)/88.37) x 100 for RRPMs. This calculates out to 4.7% and 6.4%, the average of which is 5.6%. We thus take it that the speed of curve driving will increase by 5.6% which will decrease time taken on a traverse by 5.4%.

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[15] About 56 crashes occur annually in night conditions on open road due to debris/animals/broken down vehicles/slips (which is 1.3% of all crashes from objects struck). Some of these would occur in wet conditions, and arguably would be speed related.

[16] www.niwa.co.nz/education-and-training/schools/resources/climate/meanrain

Depending on the area of New Zealand in question about a third of the days in a year have rain. Assuming travel is evenly distributed through the year, then the vehicle kilometres of travel on these sections would be 33% of 4,304 million vehicle kilometres travelled on roads classified as curved in the One Network Road Classification or 1,420 million vehicle kilometres. If we assume a baseline speed of the average of the baseline speeds in the trial, the baseline speed will be (84.95+88.37)/2 or 86.6km/h. At that average speed, if all the travel on those 120 wet days is in the wet then the time saved would be 16.4 million hours. Using the previously used values of time this adds up to a total savings in travel time cost of $531 million. This would reduce proportionately, as not all travel on days with rain would be during rainfall, so more conservative figures were established in table 6.2 to account for the lower proportion of travel occurring in the wet. Assuming no detriment to safety, all the costs relate to the installation of the markings. The enhanced markings would be used on the entire length which is 3,683.5km. They would also be laid in both directions with those in the opposite direction at the centreline rather than the edge of the road,[17] which means a total length of markings of 7,367km. As the study showed no change for ATPs this analysis will look at RRPMs and structured markings only.

RRPMs cost around $10 to buy and $10 to install. To install 7,367km of RRPMs at a spacing of 20m would cost $3.684 million. It would cost the same to buy them. If it is assumed their attrition rate is 10% a year, then the annual ongoing cost would be 10% of $7.368 million or $736,800 excluding the travel costs associated with the installations. Table 6.2 shows wet travel social cost savings by proportion of all wet day travel occurring during rainfall, assuming 120 wet days per year, compared with the RRPM acquisition and installation costs.

Table 6.2 Wet travel social cost savings by proportion of all wet day travel occurring in the wet assuming 120 wet days per year compared with the RRPM acquisition and installation costs

Proportion of all wet day travel occurring in the wet (assuming 120 wet days in the year)	Wet travel social cost savings from enhanced curve delineation in the wet ($million)	Installation cost of RRPMs	Annual costs of replacing RRPMS after initial installation	Installation costs of structured markings ($million)	Annual costs of replacing structured markings
100	531	$7.4 million	$740,000	33	3.3
60	318	$7.4 million	$740,000	33	3.3
40	212	$7.4 million	$740,000	33	3.3
20	106	$7.4 million	$740,000	33	3.3

Structured markings are not regularly used by contractors, and the one-off price for this project was $8,000/km (as it was a short distance trial, it did not have economies of scale). Comparisons with the prices charged for this project for ATPs compared with the prices supplied to us by the Transport Agency indicate a contractor price might be in the region of $4,500/km. Using this assumption 7,367km of these markings would cost $4,500 x 7,376 or around $33 million to install. Using an attrition rate of 10%, there would be a $3.3 million annual cost.

[17] The inside edgelines of the curve and centre line are selected as these represent the tangent point of the curve (see Land and Lee 1994). The tangent point (or inside curve) is where drivers look when they judge curve tightness. For a left turn curve the left edgeline becomes the inside curve, for a right-turn curve the centreline becomes the inside curve (on roads where drivers travel on the left side of the road).

For both types of delineation, it is clear the travel time savings outweigh the costs by an extremely large margin. It must be remembered, however, that these time savings may not necessarily occur at different sites under different conditions. Also, the structured markings appear much more expensive than the RRPMs in initial cost by a factor of four, and by a similar factor for upkeep. Thus, assuming no safety externalities, and the assumptions used, both types of markings are very cost effective, but the RRPMs are much more cost effective.

6.3 Conclusions

Overall, it would appear cost effective to keep EMPs on straight stretches of rural roads (as they have about a 3:1 estimated benefit–cost ratio). Advanced curve delineation systems in the form of RRPMs and structured markings also appear cost effective, with the RRPMs being a cheaper option from the trials carried out.

The wet weather trials were of a limited nature, being at only two locations and during the day (because of limited night wet data). More comprehensive trials including night trials in wet conditions would be necessary to make a fully informed choice, especially around the use of structured markings. However, there was evidence RRPMs performed well in wet night and wet day conditions, and were about a quarter of the cost. This means until more evidence regarding the efficacy of the structured markings is available, RRPMs are recommended as the preferred option.

7 General discussion

7.1 Targeted delineation (trial one)

7.1.1 Evidence of better driver risk adaptation

Evidence revealed improved risk adaptation of driver behaviour to the curve at night when EMPs were targeted at the curve. First, drivers showed greater reductions in speed when transitioning from the straight section to the curve in the targeted EMP treatment. Second, there was evidence to support heightened driver attendance to the risk at the curve, with significantly higher hand positions on the steering wheel at night after EMP treatment compared with the optimal visibility condition during daylight.

The findings provide support for the underlying philosophy behind targeting higher risk environments with the goal of self-explaining delineation, where drivers intuitively detect changes in risk and adopt appropriate behavioural adaptations, such as effective speed management. Indeed, drivers showed some sensitivity to the delineation conditions, so the premise around targeted delineation is supported, which departs from the existing 'more is better' hierarchical approach for our rural delineation (ie RTS 5). This has already been trialled effectively with New Zealand drivers in urban conditions, where road treatments guided drivers to make appropriate speed choices (eg Charlton et al 2010).

7.1.2 New evidence of edge marker post benefits

Despite heightened awareness at curves, the specific intervention trialled with targeted EMPs does appear to increase speeds on straight sections of road. Anecdotal evidence from the qualitative component of the questionnaire supports this finding, by suggesting the EMPs provide drivers with distance and speed cues. Indeed, this suggestion aligns well with Gibson's (1979) psychological and ecological theory on visual perception cues. Specifically, Gibson reasons that one of the key factors in successful depth perception (especially during movement) is through the use of 'invariant information,' which is derived from visual cues that remain constant relative to the wider visual field. The theory proposes individuals are able to get a better sense of distance and speed by using cues that have consistent spacing, acting as a reference point.

Therefore, the current findings match with Gibson's work as they suggest, due to the consistent and predictable spacing of EMPs, participants are better able to monitor their speed by having more (albeit unconscious) sensitivity to their movement due to the constant reminders of the passing posts. While similar predictable roadside cues are present during the day (such as power poles or fence posts), this information disappears at night, making the visual information provided by EMPs relatively unique.

As a result, targeted use of delineation should either not be performed with EMPs (as they provide a valuable role at night) or should be done with an increase (as opposed to reduction) in EMP use. However, for the latter option, EMP density does typically increase at curves (to ensure at least four EMPs are visible at any time). Alternative methods to highlight hazards via delineation should still be pursued. This finding also aligns with the practical context of road engineering guidance adapted for New Zealand conditions. New Zealand shares a lot of its road engineering guidance with Australia, but because of the vertical curvature of New Zealand's hillier road geometry this arguably makes EMPs a more critical device.

7.1.3 Driver comfort with targeted delineation

Hand positions were higher when coming into the curve at night. This increase in the number of hands on the top half of the steering wheel relates to a state of heightened awareness, as a consequence of the EMPs placed at the curve, as opposed to a general discomfort with the removal of EMPs. The logic behind this is 1) there was no reduction in the delineation at the curve that would influence a driver's ability to safely negotiate the curve, and 2) if drivers were very uncomfortable with the curve, they would also reduce their overall driving speed. The fact there was no overall drop in speed supports the hypothesis that the delineation environment was at a level requiring only adaptation through heightened driver awareness. Increasing awareness like this, as opposed to attempting to maintain heightened level of arousal for an extended period of time, arguably may also have a positive impact on mitigating driver workload and fatigue.

7.1.4 Public perceptions of delineation and maintaining the status quo

Drawing from the indicative survey data, it can be said the public may be generally unaware of specific delineation markings, with only a third of drivers travelling through the site noticing any change in the road environment. Furthermore, only 16% of people could say they noticed the EMPs had been altered. Such findings indicate that the impact of delineation on driving behaviour is largely implicit, as drivers are generally unaware of their presence.

This suggests that the observed behaviour changes (eg the higher hand positions at the curve) were likely to be occurring due to implicit adjustment to the environment rather than from explicitly noticing the lack of EMPs. This aligns with previous research around road signage space, where drivers implicitly or unconsciously process the information, as observed by reduced speeds around warning signage, but have low recall or comprehension of that same signage (eg Fisher 1992; Charlton and Baas 2006a).

Building on this interpretation, it would seem whatever the perceptual benefits are of delineation, the public in general would not be able to consciously discriminate the benefits derived from different delineation components, (eg being able to discern the benefit from the presence of EMPs compared with that of painted lanes or chevrons). Consequently, this lack of differentiation would result in the formation of a 'global' perception of delineation where all components are perceived as being equally necessary in creating a safe, driving environment. This was also supported by drivers' comments within the survey, where there appears to be a 'more is better' mentality amongst many drivers.

However, for those who do notice the change, the public backlash is evident, and quickly picked up in the media (eg Basham 2012a; Basham 2012b). The survey findings revealed that, when explicitly informed about the changes, drivers using this rural road disliked the removal of EMPs. Drivers also reported a significant decrease in ease of seeing upcoming changes to the road at night, in particular changes to the road curvature, even though the curve delineation had not altered. However, to put this in context all the 13 subjective performance factors related to the use of targeted EMPs led to significantly lower performance ratings, indicative of a loss aversion bias, where any perceived reduction is disliked.

Loss aversion is a common bias, especially when something considered to be 'the norm,' or part of the 'status quo', is removed. When people have no clear preference for or understanding of a particular choice, they are more motivated to maintain what they already have as they place greater value on what is lost than what stands to be gained (eg Kahnenman and Tversky 1979; Tversky and Kahnenman 1991). Thus, the combination of these factors results in a situation where the public are implicitly motivated to be averse to changes to road safety delineation. This aversion may also help explain why there are very few trials where road safety features are removed to test effectiveness.

Overall, greater transparency around how delineation is optimised across the network may be the solution. This is supported by the survey data, where it was shown that most drivers, though disapproving of the removal of EMPs, indicated they would be happy with the changes if the cost-savings made from the removal were invested back into other local road safety initiatives. This is particularly important, as many of the improved changes could be much subtler than removing EMPs. For example, if changing to a roadmarking that has high performance in the wet but otherwise has no detectable difference, the improvement and why it was made should be communicated to the public. Delineation at night and delineation in wet conditions were rated as the fifth and seventh most important areas to improve (out of nine improvements), and certainly were more cost effective than the top ranked increasing the width of the road or improving the road surface quality.

7.1.5 Night driving speeds and delineation

There was an overall night profile indicating that night driving was faster, including higher 85th percentile speeds and non-compliance with the speed limit. The night finding could be explained by factors such as different drivers travelling at night (eg fewer older drivers), ability to see other vehicles earlier (based on headlights), driver expectations of fewer other road users (such as cyclists or livestock on the road), and driver expectation of a lower level of speed limit enforcement. In terms of speed choice, it also indicates that drivers using the road at this time either believe the delineation environment provides enough guidance to travel at these speeds at night, or that they are simply less aware of their speed at night. The evidence in this study certainly indicates that the tendency to drive faster at night could be exacerbated by the removal of consistently spaced perceptual cues (in this case EMPs) to intuitively heighten driver awareness of speed.

7.2 Wet weather delineation (trials two – four)

Trials two, three and four examined improved wet weather delineation treatments, with three different features that varied in height and material, namely: RRPMs, ATP and a structured marking. The ATP and structured markings were selected based on their properties in terms of offering better drainage in wet weather and improved retroreflectivity due to a raised profile compared with traditional markings. In rain conditions, the structured marking and RRPMs led to an increase in driving speed (closer to daytime dry speeds), while the ATP marking did not have any detectable effect.

7.2.1 Marking brightness when raining – structured markings

The structured marking trial revealed the chosen driving speeds in rain were similar to speeds that would normally occur in dry road conditions (ie speeds of around 89km/h in the structured marking in rain compared with 90km/h with the baseline marking in dry conditions). This speed change did not occur in the baseline rain condition (where drivers were about 4km/h slower in the rain). Also, there was no observed change in driver steering-wheel hand positions, indicating no detectable change in driver comfort. Because the only environmental change was one designed to improve visibility in rain, this behavioural evidence indicated the structured marking provided a better visual environment for drivers, and so was a successful intervention for rainy conditions (at least during daytime rain).

Less intuitively, it was found the physical measures of retroreflectivity (which indicate marking performance) did not show a large improvement in retroreflectivity for the structured marking when compared with baseline. One explanation relates to the fact that the retroreflectometer takes average area measurements, and the retroreflective beads placed in the marking appeared to have only settled in parts of the line (ie were inconsistent, see appendix D). Therefore, in situations like the structured markings (where there may be bright, reflective components as well as dull components) these effects may have averaged out. Such a possibility means a solid white line can have a retroreflectivity reading of about 50 while a structured marking can also have a reading of 50, which on the other hand, can still have an effect on driver behaviour due to parts of the line actually having higher retroreflective readings (which may be what the human eye detects).

Although this hypothesis requires greater investigation, if correct, it would mean the performance metric of average retroreflectivity does not align with how we visually interpret markings. Better metrics might include maximum retroreflectivity or 85th percentile retroreflectivity. In other words, perhaps the line is as beneficial as its brightest points (also assuming such an effect would still have a minimum required density or area of bright points to be effective). Certainly, the evidence suggests point sources are effective in many situations (like with EMPs or RRPMs, eg Bahar et al 2004).

It should also be noted there is a difference between visibility performance when raining compared with wet retroreflectivity testing, which could also explain why there was a difference in driver behaviour, which was measured while raining, but not in the retroreflectivemeter readings, which were simply measured under conditions where water had been poured over the line. For example, rain on a vehicle's windshield has been shown to significantly reduce driver visibility and increase driver workload (eg Zwahlen 1980; Hogema et al 2005).

7.2.2 Road condition and markings – ATP marking

There was no detectable effect of the ATP marking on driver behaviour, even though, in wet conditions, this marking had the highest retroreflectivity, a very high luminance reading, and the highest profile (or height) of the roadmarkings (which should have reduced effects from water pooling). One explanation was the baseline condition was particularly good, giving a ceiling effect.[18]

While the baseline roadmarking was not particularly unique, it performed very well (ie high retroreflectivity and luminance) because it was on a high-quality chipseal road surface. The chipseal was only three years old and used a reasonably new treatment type, a racked-in seal, which provided a coarse and textured mixture of small and large stones (ie grade 2 and 4 aggregate). Compared with a worn down or less textured chipseal, this meant the paint and beads stayed in better condition than would be expected as each chip sat proud of the road (as opposed to chip that is worn down). Dravitzki (2005) indicates that the angular and free draining properties of chipseal mean even basic markings have high levels of visibility, including in wet conditions. Chips that sit higher have a greater vertical surface area (ie distance from the sides of the stone chips), so they have effective water shedding properties, and less pooling than would be expected on less profiled or worn chipseal. The corollary of this is that more material may be needed to provide a consistent paint film thickness when applied on this type of chipseal as the surface area is larger and the material flows off the top of the chip (Dravitzki 2005).

Overall, the potential effects of the physical properties of the ATP marking suggest it is worthy of further investigation as a wet weather solution for enhancing driving safety in rural settings (especially when combined with its audio-tactile safety properties). However, it does not appear to provide additional wet weather visibility benefits when compared with a standard thermoplastic marking on high-quality chipseal. Therefore, the road quality should be taken into account as part of the decision-making process in determining the need for better delineation. Similarly, when looking at cost benefits when making road surface treatment or maintenance decisions, the calculation could consider improvements to visibility in wet conditions due to more effective delineation as an additional benefit.

7.2.3 RRPMs as an effective complementary wet weather delineation treatment

With the introduction of RRPMs, speeds coming into the curve increased during day wet conditions (to similar levels to day dry conditions), indicating that the RRPM devices are providing a distinct improvement to visibility. This is particularly significant as the road surface and baseline marking provided a very high

[18] Please also note the purpose of this study was to examine the benefits of ATP in relation to visibility when raining, so the study was not designed to determine the longer-term effects of any auditory or vibration-based benefits in supporting drivers to successfully maintain their lane position.

standard baseline condition, and so the shift in driver behaviour indicates an improvement beyond baseline visibility conditions due to the RRPMs. This finding complements earlier results which suggest the retroreflective requirements of line markings could be reduced by as much as 45% when complementary RRPMs are present (Molino et al 2003).

FHWA (2010) recommends the complementary use of RRPMs, as they can add significant improvements in visibility any time the retroreflectivity levels of roadmarkings are below 250mcd/m2/lux. To put this into context, most high performance marking standards recommend a minimum of 150mcd/m2/lux (eg European Union Road Federation 2013; NZ Transport Agency P30 2009). Following this logic, RRPMs would provide added safety value to most existing markings in New Zealand and definitely improve the safety of the markings on rural roads.

One of the key reasons that RRPMs were examined in the trial was to see whether high-quality wet weather marking could perform as well as a basic linemarking with complementary RRPMs. Based on the markings tested in this investigation, it would appear a basic linemarking with RRPMs is a better value solution for rural roads (based on cost and effectiveness in providing better visibility for the driver). A limitation of this study was that this was not tested over a longer period (where RRPMs can drop in retroreflectivity value very quickly (Migletz et al 1994)).

7.3 Limitations

7.3.1 Data collected during rainfall

For trials two to four, the driver speed data during rainfall was limited as there were few instances of comparable rainfall conditions (ie moderate rain). The exception was that moderate rain data was available for a speed comparison between baseline and RRPMs, revealing no significant differences in speed in wet night-time conditions. However, the driver speed data available during rainy conditions during the day allowed for comparisons across all three trial conditions tested (under conditions of comparable rainfall). Hand position data was not available when raining at night due to technical difficulties in collecting this data (ie the use of night vision equipment during rainfall).

7.3.2 New materials tested

The materials were not tested over their entire life cycle, so the relative degradation of different delineation treatments over time should be taken into account. Some of this degradation is known from previous literature. For example, it is especially relevant for RRPMs, which were only tested after seven weeks of use in this study. They can suffer from faster degradation than roadmarkings, but may also suffer from a greater risk of loss at curves (if there is driver encroachment).

8 Guidance for delineation on rural roads

As part of this project, practical recommendations for improvements to the existing hierarchy-based guidance for delineation on rural roads (ie RTS 5) were made for any future changes.

8.1 Cost and use of delineation in New Zealand

In terms of updating rural delineation guidance, the costs and type of delineation used have been updated to account for 2016 costs (see appendix E). Based on this data, the main new delineation practices that have been widely adopted across New Zealand are the use of wider line markings and ATP markings.

The findings of this report indicate smarter use of existing complementary devices will provide the best value solutions. For example, increased use of EMPs and RRPMs should be considered and used more consistently across network.

8.2 New materials

In terms of new materials, trials here indicate that while new markings like the structured marking were effective at providing an improved driving environment during rainy conditions, the use of traditional complementary devices like RRPMs were more cost effective. Similarly, upgrading to the best new markings, like the high-performance tape (eg 3M), while it has very high retroreflectivity properties, as discussed by the expert panel, is less cost effective for low-volume rural roads.

8.3 Targeted delineation treatments

In addition to considering different treatments based on different road hierarchies, some consideration should be given to self-explaining treatments that enable road safety practitioners to highlight increased risk to road users. For example, different treatment solutions could align with existing road categorisations, such as ‘curved’, ‘winding’ and ‘tortuous’ sections of road, based on the One Network Road Classification.

8.4 Road surface considerations

The road surface plays an important role in how effective delineation treatments are (eg Dravitzki 2005). New evidence reinforces the importance of this in poor visibility conditions, such as when it is raining. Because of this interaction effect, delineation solutions should also be related to the road surface. For example, on older surfaces with worn chip, consideration should be given to better delineation (such as complementary RRPMs) or more frequent maintenance plans.

Similarly, low colour contrast of the road surface relative to the marking could be considered. For example, surfaces in the South Island may have a lighter chip colouration and therefore may need to be brighter to be detected at the same distance. This coincidentally also aligns with high wet weather conditions in the South Island.

8.5 Targeted solutions based on where road users look

Similarly, delineation could be focused based on where road users actually look. The tangent point or inner curve where drivers look when they judge curve tightness could be the focus of renewals. This means the critical edgeline and centreline at each curve could be re-marked more regularly than the less viewed edgeline, which could reduce costs by about a sixth (if re-marked every second rotation).

8.6 Sight distance and comfort

Delineation performance monitoring could focus on metrics that are more directly meaningful to driver needs, such as sight distance. Then it would be possible to identify how people are likely to respond to different delineation solutions (eg see table 8.1).

Table 8.1 Typical expected driver responses to different sight distances

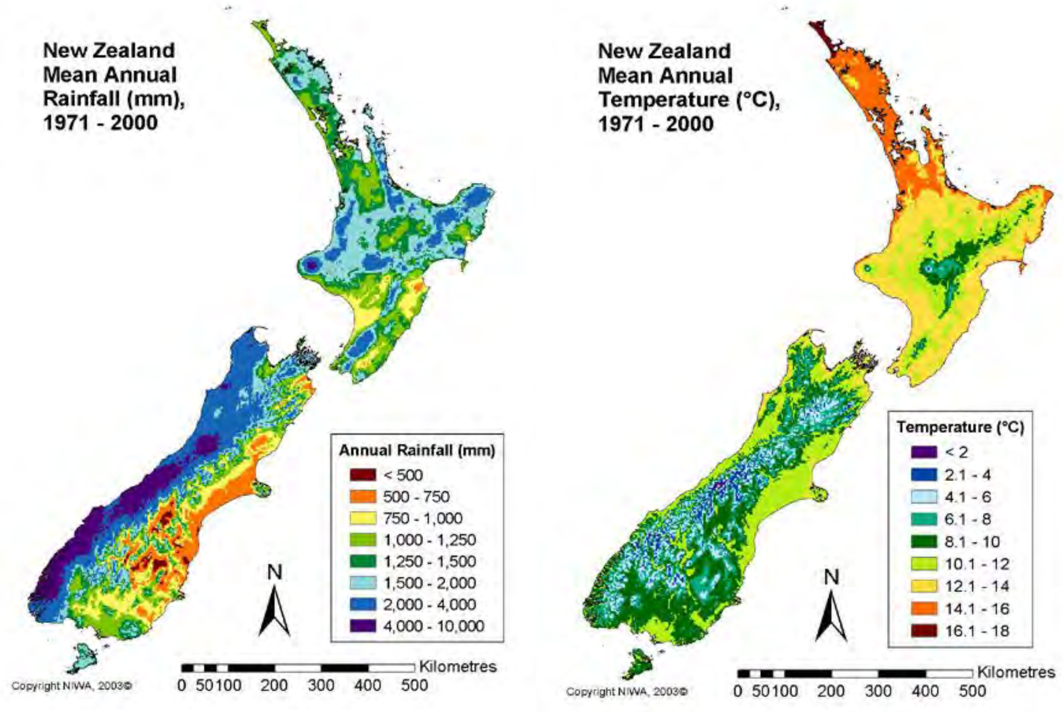
Driver responses	Minimum sight distance (seconds)
Driver comfortable	3–5
Drivers begin to adapt (reduced driver speed and variation in lane position)	1.8–2.7
Typically successful horizontal curve negotiation	1.8
Drivers begin to fail horizontal curve negotiation	1.2–1.8

8.7 Wet weather considerations

Wet weather has a significant influence on crashes. In terms of real-world behaviour change, Zwahlen (1980) found there was about a 37% reduction in average preview distance (approximately shifting from 4.9s in daytime dry to 3.0s in daytime rain conditions). Similarly, eye-blinking rate, a proxy measure of driver workload was about 3.5 times higher in rainy conditions (1.82 blinks per minute in dry to 6.67 blinks per minute in rain (Zwahlen 1980)).

This needs to be considered in terms of what is an acceptable sight distance for areas with high rainfall. In RTS 5 an area with 1,000mm of rain per year was used as a basic suggested threshold for determining locations with exposure to rain and considering wet weather delineation devices (such as EMPs and RRPMs). However, this does seem to be a low threshold based on NIWA data (eg see figure 8.1 left). Similarly, the locations with rainfall also align closely with locations with exposure to other poor visibility conditions, such as snowfall, which can be indicated by lower temperatures (see figure 8.1 right).

Figure 8.1 Annual rainfall (left) and temperatures (right) for New Zealand from 1971–2000 (Source: NIWA)



One suggestion would be to provide a traffic-light based high, medium, low treatment threshold to consider wet weather delineation (for example, see table 8.2). In an Australian study, Keay and Simmonds (2006) found a reasonably linear increase in crashes in urban environments when comparing wet and dry crashes, from about 2–5mm daily rain increasing crash likelihood by about 10% through to 20mm or more increasing likelihood by about 60%. In practical terms, this may mean increasing the delineation hierarchy by one level to account for increased exposure to reduced sight distances (particularly on low-volume rural roads). It is recommended a spatial crash analysis looking at poor visibility crashes (eg rain or snow) be performed to support accurate thresholds.

Table 8.2 Suggested thresholds for improved delineation solutions in rainy conditions

Exposure to rain	Rainfall threshold (annual rainfall in mm)	Treatment considerations
Low rain exposure	Less than 1,000	No additional treatment
Moderate rain exposure	1,000–1,499	Moderate treatment (consider partial use of EMPs and RRPMs, especially at curves)
High rain exposure	1,500 or more	High treatment (consider full use of EMPs and RRPMs, and higher profile roadmarkings as appropriate)

8.8 Overall delineation treatment hierarchy

Applying the appropriate delineation treatment to different road types will always require expert evaluation. However, building from the original RTS 5 document (Transit NZ 1992) a draft hierarchy has been developed as a tool to assist expert decisions (see appendix F). Several factors need to be considered where a more rigorous treatment selection could be applied, for example, where there is a higher crash risk indicating an issue with visibility at night or in the wet, there is likely to be a case for moving up in the delineation hierarchy. Similarly, the road width may be preventative in the full use of roadmarking treatments in some instances (ie the use of edgelines and a centreline when sealed road widths drop below 5m). Factors to be considered in delineation treatments include:

- crash risk due to road visibility (eg loss of control and head-on crash types at night or in wet conditions)
- traffic volume (especially high night travel volumes)
- frequency and degree of horizontal and vertical curvature (curved, winding, tortuous)
- out of context curves
- frequency of poor visibility weather (including areas with high rainfall, fog, mist, snow)
- available sealed road width
- continuity (with surrounding road types)

For simplicity, the hierarchy has been linked to the One Network Road Classification. A brief summary of the benefits of different delineation treatment devices has also been added to assist decision making. It is important to note this is only an indicative hierarchy intended to be further developed prior to implementation as a practical guidance tool, and even then it will only be used as a guide.

9 Conclusions

As a visual guidance tool, delineation devices have the ability to improve poor visibility environments (such as at night or in rainy conditions) in such a way to enable drivers to preview the road ahead as if they were driving in 'as good as dry day conditions'. Developing a best value delineation approach is all about understanding the effectiveness of different delineation solutions, so safety, cost, journey time and comfort can be optimised across the network.

New evidence from the current investigation revealed many of the delineation tools used had additional driving navigation benefits, such as EMPs providing cues to distance and speed at night (as well as long-distance cues to road curves). There is also some evidence to support the use of delineation variation to intuitively guide drivers to be more attentive to higher risk locations, following the concept of self-explaining roads (eg Theeuwes and Godthelp 1995). Finally, in terms of wet weather treatments, new material applications (such as higher profiled structured markings) resulted in better performance when it is raining. However, the combination of a good quality thermoplastic roadmarking with RRPMs is still more cost effective for rural settings, especially if the thermoplastic marking is on a high-grade chipseal (ie large stones), that already holds a high profile and good drainage (as opposed to a worn road surface).

Based on the effectiveness of delineation on driver behaviour and safety, more effort should put into the standardised monitoring of specific types and qualities of delineation; and better monitoring and understanding of the contribution of the pavement surface to the effectiveness of the delineation treatment. Such initiatives should perhaps set a higher standard of performance on roads that have higher importance (ie for New Zealand following the One Network Road Classification system), or have higher exposure to poor visibility conditions (ie high annual rainfall). Actions of this kind would further our understanding of how to best optimise delineation performance, though would still require a shift from the culture of performance monitoring, which focuses on confirming observed underperformance, to proactive mapping of asset performance using meaningful measures (such as sight distance). Initiatives of this kind are particularly relevant and sit at a critical stage of change, given there is an ageing population, as well as the rapid emergence of new technology that could utilise delineation if it were simply more consistent (ie autonomous vehicles).

10 Recommendations

The following recommendations are made based on the findings from this investigation:

- Edge marker posts (EMPs) are cost effective, all weather delineation tools with safety value and should be used on all road hierarchies (on straight stretches and curves). This study has provided unique information that supports their use as critical guides in night-time driving conditions as they are evenly spaced at 100m gaps and enhance judgement of speed and distance. Removing them from straight stretches of road would have unexpected and negative influences on speed.
- Develop national guidance for consistent delineation treatments to support self-explaining road designs. This is where the driver is intuitively cued to an increase in actual risk through an increase in delineation, giving the driver explicit signals to adapt their behaviour (eg by increasing their attentiveness or reducing their speed). Such guidance could align with existing road categorisations, such as 'curved', 'winding' and 'tortuous' sections of road, based on the One Network Road Classification. This is also relevant for rapidly emerging technology (such as autonomous vehicles).
- The RRPMs are a cost-effective, inclement weather solution that should be used increasingly on most rural roads, especially in areas with increased exposure to wet weather and wet weather crashes. They add complementary safety value even to high-quality markings (at least in the early phase of their life cycle).
- RRPMs also prove a highly retroreflective point source delineation treatment adds increased visibility to a traditional continuous line treatment when driving in the rain. Further work could examine point source treatments either without continuous roadmarkings, or with less frequently maintained roadmarkings.
- Though the structured markings appeared to improve visibility for drivers in rainy conditions, there were issues with the particular marking trialled. As a result the physical performance properties (retroreflectivity and luminance) were not high, presumably due to bead loss. Further testing is recommended.
- Tangent point delineation solutions should be trialled at curves. Delineation is targeted to the inner curve where drivers look when they judge curve tightness. This means for a left-turning curve, the left edgeline and centreline at each curve could be re-marked more regularly than the less viewed right edgeline, which could reduce costs by about a sixth (if re-marked every second rotation). Alternatively, better materials or wider markings could be tested using this targeted approach.
- There is some evidence of a gap between actual behavioural performance when driving in the rain and retroreflectometer readings in wet conditions. This should be examined more closely, as it appears the human eye detects some markings better than expected in rainy conditions. There is potential for identifying further improvements for new delineation treatments as well as possible cost savings.
- The evidence here suggests techniques to provide a textured road surface (like the 2/4 aggregate used in trials) also appear to have additional visibility effects, providing not only better grip and drainage, but also better wet weather delineation performance. These added effects could be considered in road surface decision making.
- Consideration should be given to providing better communication plans and increasing transparency with the public around any removal or reduction in levels of service for high-visibility infrastructure (such as delineation). The findings suggest public backlash can be mitigated if the public understands why there has been a shift in spending. A proactive communications plan allows the development of a

public profile of the safety interventions being focused on, and why this is important to optimise area-wide safety at the local level.

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Appendix A: Delineation survey

NZ TRANSPORT AGENCY
WAKA KOTAHI

OPUS

RURAL ROAD VISUAL TREATMENT SURVEY

The purpose of this survey is to investigate roadmarkings and other "visual guides" provided to help you travel on rural roads. We want to understand your perceptions and satisfaction with different road marking treatments so that user needs are considered.

We have recently run a short trial in the Masterton area, so we are particularly interested in people who drive in this location.

Important information about this survey:

- Please only complete this survey if you have driven in or around the Masterton area. If you have not, please do pass this on to someone else in your household who does
- Your participation in this survey is completely voluntary
- Your answers to the survey questions are confidential and will be used for research purposes only
- As a small token of appreciation for completing this survey we encourage you to enter a **PRIZE DRAW for $500 worth of MTA vouchers** (please see the attached prize draw card for further information)
- Your survey and prize draw card can be sent back to us in the freepost envelope provided (your details will not be linked with your survey response or used for any other purpose).
- This survey should only take you about 15-20 minutes to complete.
- If you have any questions or want to discuss any part of the survey, please contact me at: Jared.Thomas@opus.co.nz or call me on (04) 5870675.

Terms used in this survey...

- *By **Rural Roads** we mean roads in rural areas with speed limits over 70 kms per hour. Generally these roads have no street lighting.*
- ***Road markings** for the purpose of this survey include:*
  - *Markings on the road, such as painted centrelines and edge lines, rumble strips, and 'cats eyes' (the raised reflectorised markers).*
  - *Roadside markings, such as edge marker posts (pictured right)*

General satisfaction with New Zealand's rural road network

1. Thinking about the rural roads with which you are most familiar...						
	Poor	Fair	Good	Very good	Excellent	Not sure
How would you rate the quality of rural roads in New Zealand?	○	○	○	○	○	○

2. Still thinking about the rural roads with which you are most familiar...						
	A lot worse	A little worse	No different	A little better	A lot better	Not sure
How would you rate the quality of the rural roads now compared to 2 years ago?	○	○	○	○	○	○

We'll now ask you to rate some of the features of New Zealand's rural road network. Again thinking about the rural roads with which you are most familiar, how would you rate the...						
	Poor	Fair	Good	Very good	Excellent	Not sure
3. Safety design and features (e.g. design of bends and provision of guard rails)	○	○	○	○	○	○
4. Quality of the surface and smoothness	○	○	○	○	○	○
5. The width of the road and lanes	○	○	○	○	○	○
6. Road signs (e.g. warning and direction signs)	○	○	○	○	○	○
7. Management of environmental impacts (e.g. noise, pollution, rubbish)	○	○	○	○	○	○
8. Construction and completion of rural roading projects (e.g. quality and duration)	○	○	○	○	○	○
9. Road markings (e.g. painted lines, cat's eyes and edge marker posts) during DAYLIGHT	○	○	○	○	○	○
10. Road markings (e.g. painted lines, cat's eyes and edge marker posts) during NIGHTTIME	○	○	○	○	○	○
11. Road markings (e.g. painted lines, cat's eyes and edge marker posts) during WET CONDITIONS	○	○	○	○	○	○

Experience Driving in the Masterton Area

12. Do you ever drive on rural roads in or around the Masterton area?	
○	Yes, regularly
○	Yes, but not regularly
○	No

The picture below shows the main Masterton bypass road, Paierau Road. In a recent trial, edge marker posts were temporarily removed from two straight sections of road (marked in red).

13. Do you ever drive through the Masterton bypass road (Paierau Road, shown above)?	
○	Yes, regularly
○	Yes, but not regularly
○	No
○	Not sure

14. Again, looking at the picture above, did you notice this trial condition with edge marker posts removed on the straights? *[It happened on the week of Monday 21st July-Friday 25th July].*	
○	No, I did not drive through the site this week
○	No, I did drive through, but did not notice any change to the site
○	Yes, I did notice that something had changed, but was not sure what it was
○	Yes, I noticed that the edge marker posts had been removed

Scenario 1

Edge marker posts on Straight (as well as edge lines, centre lines and cats eyes)	**Edge marker posts at Curve** (as well as edge lines, centre lines, and cats eyes)
	

Think about what it would be like driving on rural roads, including driving at night, with the specific package of road marking treatment as indicated in these pictures *(with edge marker posts on both straight and curved sections of the road).* How would you rate Scenario 1 for...

	Poor	Fair	Good	Very good	Excellent	Not sure
15. Viewing distance of the road ahead	○	○	○	○	○	○
16. Ease of guessing an oncoming vehicle's speed or distance	○	○	○	○	○	○
17. Keeping you alert	○	○	○	○	○	○
18. Your ability to travel at daytime speeds during night conditions	○	○	○	○	○	○
19. Your comfort when driving at night	○	○	○	○	○	○
20. Ease of driving for less experienced drivers	○	○	○	○	○	○
21. Ability to keep a safe lane position if there was glare from an oncoming vehicle's headlights	○	○	○	○	○	○
22. Ability to safely follow another vehicle closely (prior to overtaking)	○	○	○	○	○	○
23. Your comfort when driving in heavy rain	○	○	○	○	○	○
24. Ease of seeing upcoming changes in the road at night (e.g. curves)	○	○	○	○	○	○
25. Overall travel time on the road	○	○	○	○	○	○
26. Overall safety	○	○	○	○	○	○
27. Overall quality of the visual driving environment	○	○	○	○	○	○

SCENARIO 2

No edge marker posts on Straight (just edge lines, centre lines and cats eyes)	**Edge marker posts at Curve** (as well as edge lines, centre lines, and cats eyes)
	

Think about what it would be like driving on rural roads, including driving at night, with the specific package of road marking treatment as indicated in these pictures *(with edge marker posts at curves and no edge marker posts on straights).* How would you rate Scenario 2 for…

	Poor	Fair	Good	Very good	Excellent	Not sure
28. Viewing distance of the road ahead	○	○	○	○	○	○
29. Ease of guessing an oncoming vehicle's speed or distance	○	○	○	○	○	○
30. Keeping you alert	○	○	○	○	○	○
31. Your ability to travel at daytime speeds during night conditions	○	○	○	○	○	○
32. Your comfort when driving at night	○	○	○	○	○	○
33. Ease of driving for less experienced drivers	○	○	○	○	○	○
34. Ability to keep a safe lane position if there was glare from an oncoming vehicle's headlights	○	○	○	○	○	○
35. Ability to safely follow another vehicle closely (prior to overtaking)	○	○	○	○	○	○
36. Your comfort when driving in heavy rain	○	○	○	○	○	○
37. Ease of seeing upcoming changes in the road at night (e.g. curves)	○	○	○	○	○	○
38. Overall travel time on the road	○	○	○	○	○	○
39. Overall safety	○	○	○	○	○	○
40. Overall quality of the visual driving environment	○	○	○	○	○	○

Still thinking only about Scenario 2, with the use of edge marker posts only on curves and not on straights, please rate your level of agreement with the following statements.						
	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Not sure
41. Overall, I am satisfied with the removal of edge marker posts on straight sections of rural roads in my region	○	○	○	○	○	○
42. Overall, I would be happy with this being introduced in my region if cost savings went back into local road safety initiatives	○	○	○	○	○	○

43. Please use the space below to provide us with any comments you have about no edge marker posts on straights, as shown in Scenario 2:

____

____

____

____

JOURNEY CHANGE SCENARIOS

44. Thinking about your travel during **NIGHT TIME** on a reasonably short journey (about 25minutes)...

Would you prefer to have a slightly longer journey to travel on a road which was ideal for night travel (e.g. high visibility and bright road markings specifically designed for night conditions), but was slightly less direct than travel on a dim road with poor night visibility?

○	Yes, but I would only be willing to add the following amount of time to my overall travel time *(please place a mark on the line to indicate how much time)* 0 mins — 0.5 — 1.0 — 1.5 — 2.0 — 2.5 mins — 3.0 — 3.5 — 4.0 — 4.5 — 5mins or more
○	No, I would prefer to travel on the dimer road and have a shorter overall travel time
○	No, I would always travel by the fastest road regardless of any road improvement

	45. Now think about your travel during **HEAVY FALLING RAIN** on a reasonably short journey (about 25minutes)... Would you prefer to have a slightly longer journey to travel on a road which was ideal for such travel (e.g. high visibility and special road markings that were specifically designed for wet weather), but was slightly less direct than travel on a dim road with poor wet visibility?
O	Yes, but I would only be willing to add the following amount of time to my overall driving time *(please place a mark on the line to indicate how much time)* 0 mins — 0.5 — 1.0 — 1.5 — 2.0 — 2.5 mins — 3.0 — 3.5 — 4.0 — 4.5 — 5mins or more
O	No, I would prefer to travel on the dimer road and have a shorter overall travel time
O	No, I would always travel by the fastest route regardless of any road improvement

ABOUT YOU...

	46. Please indicate your gender
O	Male
O	Female

	47. Please indicate your age group
O	16-24 years
O	25-34 years
O	35-44 years
O	45-54 years
O	55-64 years
O	65-74 years
O	75+ years

	48. Compared to the typical New Zealand driver, my visual ability when I drive is... (please select one option only)
O	Much better than average
O	Better than average
O	Average
O	Worse than average
O	Much worse than average

	49. How long have you been driving for?
O	Less than 6 months
O	6 months to 1 year
O	1-2 years
O	2-5 years
O	5-9 years
O	10 years or more

50. Do you try to avoid any of the following driving situations? (please select all that apply)	
○	I do not avoid any driving situations
○	Driving at night
○	Making right-hand turns at intersections
○	Driving on the open road
○	Driving in fog
○	Driving in heavy rain
○	Driving in icy conditions
○	Driving in strong winds
○	Driving in higher levels of traffic (e.g. public holidays or peak traffic times)
○	Other (please specify) ____________________

51. Please indicate which area type is most appropriate for where you currently live	
○	Urban
○	Suburban
○	Rural

52. Please indicate your total annual household income	
○	$20 000 or less
○	$20 001-$30 000
○	$30 001-$40 000
○	$40 001-$50 000
○	$50 001-$60 000
○	$60 001-$70 000
○	$70 001-$100 000
○	$100 001-$150 000
○	$150 001 or more
○	Prefer not to say

53. Are you happy to participate in an additional survey about this topic in the future?	
○	Yes. Please provide your contact email or name and address details here: ....
○	No

54. Do you have any other comments about rural road marking treatments or this survey?
____
____
____
____
____
____
____
____
____
____

Many thanks for your contribution. Please remember to fill in the prize draw card attached.

Appendix B: Risk assessment and management

B2 Targeted edge marker post trial July 2014: risk assessment and management

B2.1 The project

Safer Journeys includes a safer speeds pillar with a key objective of providing self-explaining roads; management of the environment to provide the driver with intuitive cues to appropriate behaviours and speeds along each section of road.

The project sought to determine the influence of edge marker posts (EMPs) on route definition and driver behaviour.

This assessment evaluates the risk to road users arising from the methodology, establishes prudent steps to mitigate the risk and provides a contingency plan.

Risk to workers engaged on the site works and survey is managed by an appropriate traffic management plan.

B2.2 The methodology

Following a base line survey, it was proposed to remove the EMPs along a straight section of rural road and monitor subsequent driver behaviour in daylight and in darkness (a more detailed description of the site is in section 2).

Other existing signs, delineation in the curves and hazard markers were to remain in place.

B2.3 Discussion

Traffic services in New Zealand generally follow international practice.

Low-volume roads may not have any markings or delineation and limited to an occasional sign where 'in the opinion of the controlling authority a condition or risk is not evident to approaching drivers and constitutes a hazard.'

As roads carry greater volumes, feature increasing speeds and generate greater driver expectations, the controlling authority introduces (not necessarily in the following order):

- centreline markings
- edgeline markings
- edge marker posts on curves
- edge marker posts on straight sections of road
- raised reflective pavement markers
- chevrons on curves (PW-67)
- curve advisory signage (advance warning, PW-66, possibly PW-67s)

……or varying combinations of the above.

The controlling authority is required to have a traffic services policy which takes account of the demands across the network and affordability; with a focus on meeting reasonable driver expectations. This policy has regard to a range of Transport Agency and peer group policies and standards. With the exception of curve advisory speeds management, there is a goodly measure of engineering judgement required to develop an effective policy.

B2.4 Risk assessment

The section of road mooted for study is straight and features marked centreline and edgelines along with centreline RRPMs. There are well maintained clear zones.

None of the delineation and advance warning associated with curves is to be modified.

From the section 7 it is apparent there is a range and a hierarchy of delineation measures available to the controlling authority and, further, that engineering judgement forms a part of decision making. This proposed survey acknowledges there is no current international data on the specific effects of EMPs on a straight section of the road.

This assessment is based on the premise that following removal of the EMPs the balance of traffic services meet the installation and condition standards adopted by the controlling authority.

There may be a 'moderate' risk if a wet pavement affected the function of the markings and RRPMs. In any event, wet conditions are likely to affect behaviour and therefore the validity of the survey data.

My overall assessment is that the risk associated with this proposal is 'low'.

B2.5 Risk management

Work is to be undertaken in terms of an approved Traffic management plan.

The balance of traffic services must meet the controlling authority's standards.

The survey is to be undertaken in dry, fine conditions.

That should an unforeseen hazard arise:

- the survey is discontinued
- the survey will not resume until the hazard is safely managed
- if the hazard cannot be safely managed, temporarily reinstate delineation with Code of practice for temporary traffic management compliant cones.

Safety assessment prepared by:

Mike Petersen, Projects Manager, Opus International Consultants, Blenheim,17 July 2014.

Appendix C: Survey result tables

Table C.1 Scenarios where driving is avoided

Scenarios where driving is avoided	N	Yes		No	
		Frequency	Percentage	Frequency	Percentage
I do not avoid driving in any situations	65	36	55.4%	29	44.6%
Driving at night	65	5	7.7%	60	92.3%
Making right hand turns at intersections	65	6	9.2%	59	90.8%
Driving on the open road	65	2	3.1%	63	96.9%
Driving in fog	65	9	13.8%	56	86.2%
Driving in heavy rain	65	7	10.8%	58	89.2%
Driving in icy conditions	65	20	30.8%	45	69.2%
Driving in strong winds	65	12	18.5%	53	81.5%
Driving in higher levels of traffic	65	12	18.5%	53	81.5%

Appendix D: Edgeline treatments

The edgeline treatments for the structured marking at site one and the ATP marking at site two can be seen in figures D.1 and D.2 respectively.

Figure D.1 Site one baseline edgeline marking (showing marking and close up, top left and right) and the structured marking treatment (showing marking and close up, bottom left and right)

Figure D.2 Site two baseline edgeline marking (showing marking and close up, top left and right) and the ATP marking treatment (showing marking and close up, bottom left and right)

Site two baseline edgeline

Close- up of site two baseline edgeline

Site two baseline edgeline with ATP

Close- up of site two baseline edgeline with ATP

Appendix E: Roadmarking and delineation device costs

The 1991 costs are taken directly from RTS 5 (Transit NZ 1992). The 2016 costs are taken from Transport Agency data for all networks (where this information was available), and supplemented by the averaged cost data from eight different contractors (only where Transport Agency data was not available). Table E.1 shows the signage and delineation device costs (broken down by cost per item and installation cost), and table E.2 shows the roadmarking costs (where installation is included in the cost). As can be seen, the main additions of commonly used delineation appear in wider line markings and the addition of ATP markings.

Table E.1 Signage and delineation device costs, broken down by per item and installation cost for 1991 and 2016 (to show where changes have occurred)

	1991 (RTS 5)		2016	
	Cost per item ($)	**Installation cost ($)**	**Cost per item ($)**	**Installation cost ($)**
Signs				
New single warning sign (600 x 600)	75	75	87	145
New single warning sign and supplementary plate	105	80	138	180
Change warning sign (600 x 600)	65	35	87	145
Add supplementary plate	45	20	45	58
New full chevron (2,400 x 600) (HI)	145	95	241	230
New half chevron (1,200 x 600) (HI)	90	80	137	192
New full chevron and supplementary plate	200	110	287	242
New half chevron and supplementary plate	160	85	167	205
Add supplementary plate	70	35	85	75
New single chevron (HI)	55	75	114	133
New bridge end marker (RM6) (HI)	15	35	24	38
New hazard marker (RM7) (HI)	5	30	17	38
Delineation devices				
Edge marker post (new) wood (HI)	10 ea	11	0	75
Edge marker post (new) plastic (HI)	10 ea	17	11	35
Raised reflective pavement marker (mono)	7 ea	9	10	10
Raised reflective pavement marker (BI)	8 ea	9	9	10
Raised reflective pavement marker (mono) (shank)	5 ea	?	8	10
Raised reflective pavement marker (BI) (shank)	9 ea	?	9	10
(HI) = high intensity reflective sheeting				
(Mono) = mono directional				
(BI) = Bi directional				
(Shank) = RRPM has a shank				

Table E.2 Roadmarking costs 1991 and 2016 (to show where changes have occurred)

	1991	2016
	Cost per km ($)	**Cost per km ($)**
Roadmarkings		
Centreline white (100mm) dashed	105 $/km	211 $/km
Centreline white (100mm) dashed reflectorised	150 $/km	221 $/km
Centreline white (100mm) dashed thermoplastic	550 $/km	2,567 $/km
Centreline white (150mm) dashed thermoplastic *	NA	3,900 $/km
Centreline white (100mm) solid	260 $/km	278 $/km
Centreline white (100mm) solid reflectorised	395 $/km	303 $/km
Centreline white (100mm) solid thermoplastic	1,050 $/km	2,733 $/km
Centreline white (150mm) solid thermoplastic *	NA	6,090 $/km
Centreline white (150mm) solid thermoplastic *	NA	8,030 $/km
Centreline yellow (100mm) solid	285 $/km	335 $/km
Centreline yellow (100mm) solid reflectorised	380 $/km	347 $/km
Centreline yellow (100mm) solid thermoplastic	1,150 $/km	3,547 $/km
Edgeline white (75mm) solid	190 $/km	225 $/km
Edgeline white (75mm) reflectorised	395 $/km	261 $/km
Edgeline white (75mm) thermoplastic	850 $/km	2,970 $/km
Continuity line white (200mm)	660 $/km	606 $/km
Continuity line white (200mm) reflectorised	825 $/km	562 $/km
Continuity line white (200mm) thermoplastic	1,550 $/km	4,967 $/km
Edgeline white (100mm) reflectorised	NA	290 $/km
Edgeline white (100mm) thermoplastic	NA	3,233 $/km
Edgeline white (150mm) reflectorised	NA	436 $/km
Edgeline white (150mm) thermoplastic *	NA	5,950 $/km
Edgeline white (200mm) reflectorised	NA	633 $/km
Edgeline white (200mm) thermoplastic	NA	6,040 $/km
Roadmarkings (ATP)		
Centreline white (150mm) dashed thermoplastic/cold applied plastic	NA	3,422 $/km
Centreline white (200mm) dashed thermoplastic/cold applied plastic	NA	4,860 $/km
Centreline white (150mm) solid thermoplastic/cold applied plastic	NA	4,682 $/km
Centreline white (200mm) solid thermoplastic/cold applied plastic	NA	6,580 $/km
Centreline yellow (150mm) solid thermoplastic/cold applied plastic	NA	4,655 $/km
Centreline yellow (200mm) solid thermoplastic/cold applied plastic	NA	6,355 $/km
Edgeline white (150mm) thermoplastic/cold applied plastic	NA	5,123 $/km

Note: Costs indicated by an asterisk (*) have been provided by NZ Transport Agency data

Appendix F: Rural road delineation draft hierarchy

The layout and benefits of different delineation materials are summarised in figure F.1 below.

Figure F.1 The layout and summarised benefits of different delineation treatments

Delineation material type	Description of benefits
Edge marker posts	• Long distance horizontal and vertical curvature cues • Long distance cues help with driver speed selection for upcoming curves • The only devices here with enough vertical height to provide vertical curvature cues • Provide unique speed and distance cues at night on straight sections of road (due to the even spacings at 100m intervals) • Tighter spacings reflect the degree of curvature
Edgeline marking Centreline marking	• Provide short to medium distance cues to help negotiate upcoming curves and select appropriate speed choices • Brighter markings have higher retroreflectivity values that indicate performance with good performance at 100Rl and high performance at 150Rl or above • The width of these markings has also been used to improve visibility more effectively than increasing retroreflectivity beyond 100Rl (with widths of 150–200mm)
RRPMs	• Provide short to medium distance visibility cues • Help maintain lane position and assist with steering corrections • Provide improved wet weather visibility via a raised profile and an angled, highly reflective surface
Specialist road markings (including structured and ATP markings)	• Provide wet weather visibility through a combination of specialist beads that should maintain high retroreflectivity values in wet conditions • A raised profile that sits above pooling water. These range from a profile height of about 3mm for structured markings through to about 10mm for ATP markings (which also provide additional auditory benefits to drivers)

Figure F.2 below indicates an increasing improvement in delineation treatments as the treatment hierarchy increases by level.

Figure F.2 The draft hierarchy of delineation treatments, with recommended minimum road width, AADT and ONRC

Level 1 All ONRC (including unsealed) All traffic volumes All road widths	
Level 2 All ONRC (sealed) All traffic volumes Min road width 5m	
Level 3 Secondary AADT 500 Min road width 5.5m	
Level 4 Secondary/arterial AADT 1,000 Min road width 6.0m	
Level 5 Regional/arterial AADT 2,500 Min road width 6.0m	
Level 6 Regional/arterial AADT 3,000 Min road width 6.0m	

Note 1: Under specific circumstances expert judgement should be used to consider moving up or down the hierarchy based on factors like: continuity of delineation, crash history, road curvature, probability of poor visibility (such as high rainfall or high night traffic flow locations), or specific road user types (such as high tourist traffic locations).

Note 2: The logic for these numbers is based on 1) how delineation treatments are already being successfully applied on the New Zealand road network, 2) existing experimental data, 3) existing New Zealand data on costs and crash benefits (based on AADT and ONRC).

Note 3: AADT = annual average daily traffic; ONRC = One Network Road Classification.

Appendix G: Glossary

ATP marking	audiotactile profiled marking (also commonly referred to as rumble strips)
CAS	Crash Analysis System
effect size	When comparing the means of statistical distributions the effect size is the difference between the means divided by the pooled standard deviation of the distributions. An effect size between 0 and .2 is termed small, between .2 and .8 is termed medium, and over .8 is termed large. The effect size is an indicator of the practical size of the difference between the means.
EMP	edge marker post
$mcd/m^2/lux$	millicandela per square metre per lux
	This is the unit for measure of the retroreflectivity of a surface. A retroreflectometer measures the luminance from a surface (*millicandela*), *per square metre*, in relation to the illumination falling upon it (*per lux*) from a light source (typically vehicle headlights).
MoT	Ministry of Transport
RRPM	raised reflective pavement marker(s)
rural road	A road in a rural location with a speed limit of 70km/h or over.
TIRTL	the infra-red traffic logger (CEOS Pty Ltd, Australia)
Transport Agency	New Zealand Transport Agency
unsealed road	A road that is not covered by a bitumen, concrete or some other hard material surface. An unsealed road typically includes loose metal/gravel roads or dirt roads.