The safety benefits of brighter roadmarkings

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V.K.Dravitzki, S.M.Wilkie, T.J.Lester
Opus Central Laboratories
Lower Hutt, New Zealand

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P O Box 2840, Waterloo Quay, Wellington, New Zealand
Telephone 64-4-931-8700; Facsimile 64-4-931-8701
Email: *research@landtransport.govt.nz*
Website: *www.landtransport.govt.nz*

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Opus Central Laboratories, PO Box 30-845, Lower Hutt, New Zealand.

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An important note for the reader

Contents

Glossary

CAS	The *Crash Analysis System* is a computer system that provides tools to collect, map, query, and report on data of road crashes.
LTSA	The *Land Transport Safety Authority* is a Crown entity formed in 1998. In 2004 the LTSA merged with another Crown entity to form *Land Transport New Zealand* (LTNZ).
luminance	The luminous intensity per unit of area.
$mcd.m^{-2}.Lux^{-1}$	millicandela per square metre per lux. This is the unit for measure of the reflectivity 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*).
PSMC	Performance Specified Maintenance Contract.
risk homeostasis	The theory of risk homeostasis states that each individual has a target level of risk that they prefer to operate at, and that an individual will act to maintain their perception of their level of risk at their preferred level. The theory implies that where measures are installed that lower the perceived level of risk, an individual will increase their risk-taking behaviours until their perception of their level of risk again matches their target level of risk.
RRPM	Reflectorised Raised Pavement Marker.
Specification P/20	Performance Based Specification for Roadmarkings This Transit NZ specification requires roadmarkings to provide certain levels of performance of various characteristics, including visibility, at all times during the contract period.
Specification P/22	Specification for Reflectorised Pavement Marking. This Transit NZ specification is a methods-based specification for roadmarkings. It sets out the procedures by which particular combinations of materials should be applied to the road so as to achieve reflectorised pavement markings.

Executive summary

Purpose

Since about 1997 the brightness of roadmarkings on a number of New Zealand state highways has been increased. This study was undertaken to determine whether an increase in safety, as measured by reduced crashes, could be associated with the use of these brighter roadmarkings.

Roadmarkings on New Zealand rural roads

Specifications for the style of roadmarkings used on New Zealand roads, including those with speed limits of greater than 70 km/h, are set out in the *Manual of Traffic Signs and Markings* (*MOTSAM*), and the *Road and traffic standard 5: Guidelines for delineation on rural roads* (*RTS-5*). On New Zealand's rural roads, delineation is provided by a combination of edge marker posts carrying reflectors, painted roadmarkings, and reflectorised raised pavement markers (RRPMs). *MOTSAM* and *RTS-5* prescribe that the extent of delineation provided (intersections excluded) should increase as the annual average daily traffic (AADT) on the road increases, such that edge marker posts, then centre line roadmarkings, then edge line roadmarkings, and finally RRPMs are added progressively as traffic volume increases. As a result, the typical state highway rural road's delineation is provided by a combination of edge marker posts, centre line roadmarkings, edge line roadmarkings, and RRPMs. The typical local authority rural road will have edge marker posts and centre line roadmarkings only. Very low-volume rural roads (<100 vehicles per day) are usually without edge marker posts and are unmarked.

Historically, the required brightness of the roadmarkings has not been defined. About 1996, Transit New Zealand established a retroreflectivity (brightness level) requirement for roadmarkings on state highways. From 1997, the introduction of performance-based contracts, entailing meeting of this retroreflectivity requirement, and the development of roadmarking materials and application techniques has tended to result in:

- a significant increase in the retroreflectivity of the roadmarkings being achieved, and
- these levels of roadmarking retroreflectivity being sustained for long periods of time.

Effects of brighter roadmarkings on road visibility and road safety

Road safety and driver comfort are widely linked to visibility of the road ahead. Reflectorised roadmarkings (in mid-life condition) offer a forward visibility 20 to 40 percent greater than that offered by non-reflectorised roadmarkings (in mid-life condition). When travelling at 100 km/h, this increased forward visibility of the reflectorised roadmarkings is 0.6 to 1.5 seconds more than that offered by non-reflectorised roadmarkings.

Lack of visibility of the road ahead is considered as a possible contributing factor in crashes relating to drivers losing control of their vehicle and/or running off the road. Improved roadmarkings should improve the forward visibility for drivers and reduce the incidence of these types of crashes. The visual effect of reflectorised roadmarkings compared with non-reflectorised roadmarkings is more notable during dark conditions, rather than during light conditions, although there can be other effects, such as the reflectorised line being more durable, that will make the roadmarking also appear brighter in daylight. Therefore, while the improvement of delineation through use of reflectorised roadmarkings should decrease delineation-related crashes in both light and dark conditions, the effect should be strongest during dark conditions.

Methodology for study research

The methodology used involves a statistical comparison of crash details over time for regions throughout New Zealand that have implemented brighter roadmarkings. Regions were selected by identifying Transit New Zealand regions which had adopted performance-based methods in their roadmarking/maintenance contracts, as these contracts contained a defined level of retroreflectivity. These regions now operating under performance-based contracts were assumed to have brighter roadmarkings than under the previous methods-based approach. The treated regions were:

- Northland,
- East Waikato – Coromandel,
- East Waikato – Hauraki/Matamata,
- West Waikato,
- East Wanganui,
- West Wanganui,
- North Canterbury – Selwyn/Banks Peninsula,
- Central Otago,
- Coastal Otago, and
- Southland.

For the analyses the study periods were a 'before' period of three years, and in general an 'after' period of one to two years. The period of implementation was excluded.

To avoid any change in crash rates arising from the use of brighter roadmarkings being masked by changes in crash rates nationally, contextual analyses of crash rates on all

New Zealand's state highway rural roads and on all New Zealand's rural roads were also made.

Crash data were retrieved from the Crash Analysis System (CAS) database. Poor delineation is seldom listed as the primary cause of a crash, so the data extracted were sorted to identify a range of crash types to which delineation quality may be an underlying factor. These are taken as being mid-block crashes, primarily for loss of control movement types. Crashes under street lighting were excluded from most analyses as retroreflectivity has less effect on the brightness of roadmarkings under street lighting conditions. The subsequent statistical analysis provides the relationship between delineation quality and crash frequencies over several crash attributes, for example light or dark conditions, and road curvature. This establishes the degree of safety benefit that could be achieved by improving the quality of delineation.

Raw data analysis

The raw data shows an overall trend for the number of mid-block crashes on:

- unlit roads in the treated Transit New Zealand regions,
- on all state highway rural roads New Zealand-wide, and
- on all other rural roads over the country

to be increasing in light conditions and also increasing in dark conditions.

The 'before' and 'after' analysis considered:

- change in the average number of crashes that occurred,
- change in the ratio of crashes that occurred in light conditions to crashes that occurred in dark conditions, and
- change in the ratio of crashes that occurred on straight sections of road to crashes that occurred on curved sections of road.

Changes in crash rates

Before and after rates

The change in average annual rates of crashes 'before' and 'after' installation of the brighter roadmarkings is the most simple analysis. The variable results from this analysis gave no certain indication of a beneficial effect of the brighter roadmarkings.

Light conditions versus dark conditions

By comparing the *ratios* of crashes under different light conditions, effects arising from changes in traffic volume and any alterations to the time-split of traffic travelling in the light to traffic travelling in the dark are removed.

The hypothesis is that the introduction of brighter roadmarkings should have a stronger impact on crashes during dark conditions than during light conditions. The situation can be expressed as a matrix of light and dark crashes versus ‘before’ and ‘after’ installation of the bright roadmarkings:

Roadmarking **Light condition**	‘Before’	‘After’
Dark	*x*	*a*
Light	*y*	*b*

If the intervention has been successful, then

$$a < \frac{x \times b}{y}$$

And, if unsuccessful, then

$$a > \frac{x \times b}{y}$$

This analysis indicated that crashes in dark ‘after’ were increasing disproportionately (that is, the intervention was unsuccessful). However, the data from all rural roads and all state highway rural roads had almost identical trends, so there is insufficient evidence of any effect.

Curves versus straights

Delineation is believed to be particularly important to help illustrate curves in the road to drivers. Brighter roadmarkings should therefore help to increase the visibility of curves, and the benefit of the improvement would be demonstrated by a relative reduction in crashes on those curves. The essential hypothesis is that if drivers could be provided with an equivalent rich visual field in dark conditions as they have under light conditions, then safety would improve. Under this hypothesis, the analysis is based on a matrix:

Light Condition **Road Geometry**	Light	Dark
Curve	*a*	*c*
Straight	*b*	*d*

The ratio of crashes on curves to crashes on straights under light conditions ($a:b$) should represent the ratio possible under optimum visibility conditions. The ratio of crashes on curves to crashes on straight under dark conditions ($c:d$) should be greater than the ratio under light conditions. But, as delineation of the road increases during dark conditions, the ratio of crashes on curves to crashes on straights ($c:d$) should decrease towards the level under light conditions ($a:b$).

The comparative analysis conducted under this hypothesis showed that the ratio of crashes on curves to crashes on straights was very similar under both light conditions and dark conditions. Comparing the ratios for the 'before' and 'after' periods also shows no notable effect attributable to brighter roadmarkings. Further examination for context of this analysis compared ratios of crashes on curves to crashes on straights for all rural roads and all state highway rural roads and showed almost identical trends.

A final comparison of all low-volume (undelineated) rural roads with all state highway (well delineated) rural roads provided no indication that no or low levels of markings could be associated with a higher relative incidence of crashes on curves, compared to straights, under dark conditions compared with light conditions.

Conclusions

This study was originally directed by the hypothesis that road safety is linked to the depth and degree of forward visibility provided to drivers, and that if forward visibility was increased then a safety improvement would be observed. However, any trend toward improved safety from making existing pavement markings brighter has not been conclusive.

- The data is contradictory in that some regions indicated improved safety while others indicated worsening safety. This contradictory finding could reflect changes in crash reporting over time for some regions.
- Comparisons of trends of day/night crash ratios as well as curve/straight crash ratios for treated highways against trends for untreated rural state highways and rural roads showed no significant difference between these trends. This indicates no significant overall impact.
- The comparison of curve/straight crash ratios for day and night crashes for undelineated roads showed similar ratios for day and night. This indicates behaviour modification in response to changes in visibility, and the relationship of forward visibility of delineation to crashes may be quite strongly influenced by similar behaviour modification.

Overall it appears that identifying benefits of improving one, or only several, of the total number of elements that provide delineation by means of a before and after study of crashes will often be inconclusive and perhaps unreliable.

While the effect may have been masked by supporting delineation such as reflectorised pavement markers and edge marker posts, a comparison of unmarked roads versus well-delineated roads, gives support to the theory of risk homeostasis.

Abstract

A 'before' and 'after' style of analysis was undertaken to identify whether increasing the brightness of existing roadmarkings on unlit rural state highways had resulted in improved safety, measured as the incidence of mid-block injury-causing crashes.

Comparisons were made of average crash rates, crash rates in light conditions to dark conditions, and crashes on curves compared to crashes on straight in light and dark conditions. No evidence of altered rates could be identified.

1. Introduction

Since about 1997 the brightness of markings on some New Zealand roads has been increased. This study was undertaken to determine whether an increase in safety, as measured by reduced mid-block injury-causing crashes, could be associated with the use of these brighter markings.

Current knowledge is limited to the safety benefit of adding more roadmarkings where they were not previously used. Much brighter roadmarkings are available but they are a little more expensive, and their widespread use is impeded by a lack of knowledge of their additional safety benefits to offset this increased cost. These brighter roadmarkings are used in other countries such as Australia, the United States of America, and France, but in those countries the decision process often uses other criteria.

New Zealand needs to know the benefits of making roadmarkings brighter, as we may be missing out on some readily available safety benefits. Brighter roadmarkings should increase safety, especially for ‘run off the road’ crashes and crashes involving older drivers.

1.1 Roadmarkings within the delineation system

The style of roadmarkings used on New Zealand roads is set out in two manuals, the *Manual of Traffic Signs and Markings (MOTSAM) Volume II*, and *Road and traffic standard 5: Guidelines for delineation on rural roads (RTS-5).* On rural roads delineation is provided by a combination of edge marker posts carrying reflectors, paint markings, and reflectorised raised pavement markers (RRPMs). The guidance provided by *MOTSAM* and *RTS*-5 is to increase the extent of delineation as the average annual daily traffic volume (AADT) on the road increases. As a result, very low volume roads are usually unmarked. Edge marker posts, then centre line markings, then edge line markings and finally RRPMs are added progressively as traffic volume increases:

- The typical rural state highway has edge marker posts, centre line and edge line roadmarkings, and raised reflective pavement markers.
- The typical local authority rural road will have edge marker posts and centre line roadmarking only.

Urban roads are similar for state highways and local authority roads, and delineation consists of centre lines, roadmarkings, and RRPMs. Edge lines to denote the leftmost extent of traffic lanes are also often used. Wider roads may have extensive marked flush medians in the centre of the carriageway to assist turning manoeuvres. Edge marker posts are not used.

Pavement messages are used to a limited extent on rural roads, and extensively in urban areas. These messages are either symbolic: e.g. arrows and pedestrian crossings, or words: e.g. STOP or GIVE WAY.

Little specification is given in *MOTSAM* or *RTS-5* on the performance level of these markings with respect to brightness. Some markings, for example near hazards or intersections and no parking lines, are stated as requiring 'to be reflectorised'. This means that small glass beads are added to the surface of the marking so that it is retroreflective; that is, the marking reflects the light from a car's headlights back to its driver, thereby making roadmarkings more visible. The relative visibility effect, however, can be negligible where street lighting is good. Until about 1997 the method of applying reflectorisation was unsophisticated. Glass beads were added to the surface of the freshly applied markings, but the marking materials had been selected on criteria based more on their suitability as non-reflectorised lines. As a consequence of this unfortunate technical match of line material and reflectorising beads, retention of the glass beads was poor, and within about three months of use reflectorised lines were no better than non-reflectorised lines.

1.2 Moves to brighter roadmarking

A survey in 1995 showed that about 14% of all markings on state highways in Transit New Zealand regions were reflectorised, but generally the performance of reflectorised markings was hard to distinguish from non-reflectorised markings.

From about 1996 two main changes have occurred. The first is the development of specifications, primarily by Transit New Zealand (Transit), that have a retroreflectivity requirement for markings. The retroreflectivity value, 70 $mcd.m^{-2}.Lux^{-1}$ (30 metre geometry) is only modest by international standards. The specification types are P/20, and the Performance Specified Maintenance Contracts (PSMC). A new method type specification P/22, requires reflectorisation of the paint lines, using paints from an approved list, and implicitly intends to achieve a similar reflective value, although none is specifically stated.

Concurrently material specifications were upgraded so that marking materials were optimised to retain the reflectorised glass beads, and as a consequence markings could achieve the required level of retroflectivity for 18 months or more service life.

The introduction of a performance-based contract starting in 1997 tended to result in a significant change in marking materials, so that first, levels of reflectivity not previously attained were being achieved, and second, they were being achieved for longer periods of time, and were expected to be replaced once they fell below the minimum value.

Transit has a policy, implemented in 2001, of making all roadmarkings reflectorised, and this has been introduced progressively. The approach in local authorities is variable. Non-reflectorised markings are still used by many local authorities, but the number using reflectorised lines is increasing as the benchmark of industry best practice is increased. Some local authorities (e.g. Hastings District Council) have markings significantly more bright than the Transit standards.

1.3 Level of visibility achieved

In terms of retroreflectivity, non-reflectorised markings are about 75 $mcd.m^{-2}.Lux^{-1}$ when new, and subsequently deteriorate to about 35 $mcd.m^{-2}.Lux^{-1}$ over a six- to twelve-month period. Reflectorised markings are about 220 $mcd.m^{-2}.Lux^{-1}$ when new and subsequently can deteriorate to the same value as the non-reflectorised markings over a 12 to 24 month period. However most contracts require them to be replaced before they deteriorate to 70 $mcd.m^{-2}.Lux^{-1}$.

The same reflectivity can result in different levels of visibility or brightness depending, among other things, on the driver's age, the marking width, and the position of the marking on the road.

Table 1.1 shows the visibility of 100 mm edge lines for reflectorised and non-reflectorised lines for young drivers (15 to 35 years) and older drivers (65 to 75 years) on unlighted roads, expressed as forward viewing time at 100 km/h driving speed. At 50 km/h the distance seen is unchanged, but the viewing time ahead is doubled from that shown.

Table 1.1 Visibility of 100 mm edge line roadmarkings, expressed as seconds of forward viewing time when travelling at 100 km/h.

Driver age	**Visibility of markings (seconds)**							
	Non-reflectorised marking				Reflectorised marking			
	Dipped		Full beam		Dipped		Full beam	
	New	Old	New	Old	New	Old	New	Old
Young driver	2.7	2.0	3.0	2.2	3.3	2.7	4.4	3.0
Older driver	2.1	1.3	2.3	1.5	2.8	2.1	3.4	2.3

For much of the marking's service life it will show a plateau in the deterioration profile where initial wear has reduced the 'as new' value, but final deterioration is some time away. Taking this average condition of the marking as being the mid-point between the new and old condition, the improvement of reflectorised markings over non-reflectorised markings is about 20 to 40%; that is by about 0.5 to 1.0 seconds, as can be found from Table 1.2.

Table 1.2 Visibility of 100 mm edge line roadmarkings in typical in-service condition, expressed as seconds of forward viewing time when travelling at 100 km/h.

Driver age	Visibility of markings in typical in-service condition (seconds)			
	Non-reflectorised marking		Reflectorised marking	
	Dipped	Full beam	Dipped	Full beam
Young driver	2.3	2.6	3.0	3.7
Older driver	1.7	1.9	2.4	2.9

Safe and comfortable driving requires both definition of the route ahead for about three to ten seconds driving time, and definition of the lane boundaries for about two seconds driving time. In the mixed delineation system used in New Zealand, reflectorised edge marker posts provide the long range visibility, raised pavement markers define the centre line for both the short and often medium range, and roadmarkings provide the short range visibility for accurate vehicle placement.

Relative to the markings, edge marker posts can be considered as providing a constant level of visibility over most of their typical six- to eight-year life, though there are exceptions. Raised pavement markers, over most of their three- to five-year life, can usually be seen for 150–200 metres ahead on full beam, or about 80–120 metres on dipped beam, but are much brighter when new. Usually they are replaced individually, or as blocks of several kilometres, but seldom would a full region-wide replacement be made.

This then is the nature of the improvement of roadmarkings within this study. Region-wide improvements in markings have been carried out and the changed visibility level observed as shown in Tables 1.1 and 1.2. However this improvement to the visibility of roadmarkings has occurred within a mixed delineation system in which the visibility level of other components of the delineation system has not been changed.

1.4 Crash types affected by delineation

Identifying crash types that might be influenced by improving the roadmarking delineation requires an understanding of how drivers use delineation.

Various driver models classify driver needs in different ways. In Gibson & Crooks' (1938, in Rumar & Marsh 1998) perception-based model, driver needs are defined in terms of 'visual flow over the retina' (external stimuli in front of the vehicle that indicate the border of the road). Lane markings should support and enhance the visual flow reaching the driver's eyes, thereby facilitating perception of position, course, and speed along the road. In clear daylight conditions the flow over the retina is rich and so roadmarkings are perceived peripherally and used unconsciously. In night driving, poor visibility conditions, and glare situations, the visibility of distant and peripheral stimuli used for orientation is reduced. At night, roadmarkings become more important and may be perceived in central vision and used consciously.

Rumar (1985, in Rumar & Marsh 1998) developed a task-oriented driver model with eight specified tasks. According to this model, when driving becomes more difficult (e.g. busy traffic) the driver's mental load increases. The main way drivers can reduce this mental load is by decreasing speed. The driving task most related to lane markings is maintaining track along the road, as lane markings help reduce the demand from this task.

A logical conclusion from Rumar's model is that better lane markings may allow drivers to travel faster than they would be able to if the markings were not there. Consequently, crash reduction from improved delineation may be less than expected.

In their description of how drivers use delineation, Good & Baxter (1985, in Rumar & Marsh 1998) distinguished between short-range delineation (used by drivers during reduced visibility conditions) and long-range delineation (used together with short-range guidance in good visibility conditions). Painted lines are considered good for short-range guidance, but poor for long-range guidance, while post-mounted delineators are good for long-range, but not for short-range.

Driver surveys have shown that drivers rate visual guidance as their main difficulty in night driving, reflecting the importance of the information conveyed by roadmarkings in difficult driving situations. At night, and in poor visibility conditions, the amount and quality of information available to help make predictions about the road ahead is reduced. Adequate lane markings should facilitate a driver's ability to make predictions about the road ahead, and provide feedback about the predictions made. The further ahead that lane marking helps a driver to see, the easier the driving task becomes. There is general agreement in the literature that two seconds is an absolute minimum preview time. Two seconds preview time allows the driver to maintain a safe lateral position on the road, and is just adequate for a simple braking reaction. For curving roads, poor conditions, or allowing for the unexpected, three seconds preview time is preferable (CIE 1992, in Rumar & Marsh 1998).

Liebowitz, et al. (1982, in Rumar & Marsh 1998) posited two main visual functions in driving: recognition and guidance. While the recognition function is impaired for all age groups when driving at night, the guidance function is less impaired in younger drivers than in older drivers. Therefore lane markings are particularly important for the visual guidance of older drivers driving at night.

Accordingly improved markings can be expected to improve the guidance, and reduce the crashes caused by poor guidance, in both daylight and at night, but with the improvement being much stronger for night-time crashes. There should also be additional benefits for older drivers.

The LTSA Monitoring System is a record of crash histories at sites where the road infrastructure has been modified. This system has monitored 46 open road routes which were originally delineated with only edge marker posts, and then had edge lines and other measures, such as RRPMs, installed. At the improved sites, the greatest crash reduction was seen in crashes that involved loss of control movements and objects being struck.

The Australian Road Research Board (ARRB) commissioned a literature review in which Ogden (1996) identifies potential crash reductions of 20-60% for various crash types by installing edge lines. The study identified a 20-40% reduction in permanent obstruction (0.8%) crashes and a 30-60% reduction in off-road – on straight (9.1%), and off-road – on curve (12.9%) crashes.

The LTSA Monitoring System and the ARRB literature review are but two studies of many examining the effect on crashes where additional markings were applied. Seldom, however, has the effect of making existing markings brighter been studied.

The crashes most likely to be influenced by brighter roadmarkings are those that will be initiated by incorrect lane place, or a poor sense of changes in route position within the near view. It is expected that the most affected crash type would be single vehicle 'run off the road' crashes. For this study a range of crash types will be used. First, all mid-block crashes will be considered; then second, obvious crash types not affected by delineation will be removed from the data set (such as rear end crashes); and finally only single-vehicle loss of control/run off road type crashes will be considered.

2. Methodology

2.1 General methodology

The method involves a statistical comparison of crash details over time for regions which have implemented brighter roadmarkings. Regions were selected by identifying those that had adopted performance-based methods in their roadmarking/maintenance contracts, such as the Transit P/20 specification, or Performance Specified Maintenance Contracts (PSMC). Transit P/20 is a performance-based specification that requires markings to be maintained above a minimum level of reflectivity (or brightness). The PSMCs are similar but cover nearly all of the elements of the road infrastructure, of which roadmarkings are but one part, and consequently there is a little less certainty as to the time of improvement and the extent of improvement achieved.

Table 2.1 Crash histories used for regions analysed.

Transit New Zealand region (km of roadway)	**Contract area** (if blank same as Transit region)	**'Before' period**	**Installation Period**	**'After' period**
Northland (713km)		1 Sep 1997 1 Sep 2000	1 Oct 2000 1 Apr 2001	1 May 2001 1 Apr 2003
East Waikato	Coromandel (215km)	1 Sep 1997 1 Sep 2000	1 Oct 2000 1 Feb 2001	1 Mar 2001 1 Apr 2003
	Hauraki/Matamata (329km)	1 Sep 1998 1 Sep 2001	1 Oct 2001 1 Feb 2002	1 Mar 2002 1 Apr 2003
West Waikato (289km)		1 Sep 1997 1 Sep 2000	1 Oct 2000 1 Feb 2001	1 Mar 2001 1 Apr 2003
East Wanganui (496km)		1 Sep 1997 1 Sep 2000	1 Oct 2000 1 Mar 2002	1 Apr 2002 1 Apr 2003
West Wanganui (746km)		1 Sep 1997 1 Sep 2000	1 Oct 2000 1 Oct 2001	1 Nov 2001 1 Apr 2003
North Canterbury	Selwyn/Banks Peninsula (291km)	1 Sep 1998 1 Sep 2001	1 Oct 2001 1 Jan 2002	1 Feb 2002 1 Apr 2003
Central Otago (537km)		1 Jul 1998 1 Jul 2001	14 Aug 2001 1 Jan 2002	1 Feb 2002 1 Apr 2003
Coastal Otago (743km)		1 Sep 1997 1 Sep 2000	1 Oct 2000 1 Apr 2002	1 May 2002 1 Apr 2003
Southland (774km)		1 Sep 1997 1 Sep 2000	1 Oct 2000 1 Apr 2002	1 May 2002 1 Apr 2003

Crash data were retrieved from the LTSA database. Because poor delineation is seldom listed as the primary cause of a crash, the data extracted were of a range of crash types to which delineation quality might be an underlying factor. Delineation is used subconsciously to obtain information about the route ahead, and is therefore likely to be implicated in a much wider range of crashes than those for which poor visibility would be an obvious component.

The cut-off date for crash data was 1 April 2003, one year before the data was extracted. The nature of the database is such that it is not reliably complete for the first twelve months until most crashes have been investigated, and entered.

2.2 Transit regions with upgraded markings

Transit New Zealand initiated region-wide improvements to roadmarking brightness when changing to performance-based roadmarking contracts and specifications. Transit regions known to have implemented brighter roadmarkings have been contacted to determine when this change occurred, and when the first coat of brighter marking had been applied to the highways in the contract.

The regions for which brighter marking has been implemented, and sufficient crash history developed in the after period, are listed in Table 2.1. The contract dates are used to determine appropriate crash histories for each region. In some Transit regions more than one maintenance contract exists.

Typically crash histories of three years were sought ‘before’ and ‘after’ installation of brighter markings. This was possible for all ‘before’ periods, but the ‘after’ periods were mainly one to two years only.

The total length of state highways in the above regions is 5,133 km.

2.3 Assigning crashes to Transit New Zealand region

The state highways that lie within each Transit New Zealand maintenance region were identified and the crashes that occurred on those roads were assigned to that region. Some state highway sections are excluded because:

the contract boundaries had changed; or

state highways had reflectorised roadmarkings irrespective of contract specification changes; or

the state highways were constructed during the crash history.

The length of state highway excluded from the study is 61.8 km. Table 2.2 shows the exclusions.

Table 2.2 State highways excluded from study.

Transit New Zealand region	Contract area (if blank same as Transit region)	Excluded state highway sections		
		Contract Boundary Changes	New Roads	Reflectorised for entire study period
Northland		N/A	N/A	5% before contract start
East Waikato	Coromandel	N/A	N/A	None
	Hauraki/Matamata	N/A	N/A	
West Waikato				
East Wanganui		N/A	N/A	SH3 488/0.64 – 491/4.24 (7.2 km)
West Wanganui		N/A	N/A	None
North Canterbury	Selwyn/Banks Peninsula	N/A	N/A	None
Central Otago		N/A	N/A	SH6 814/0-4.4 (4.4 km) SH8 217/0-10 (10 km)
Coastal Otago		SH85 RS62 (17.58 km) SH87 RS110 end (6 km) SH90 RS35/12.54–RS51 (3.5 km)	N/A	Reflectorised no-overtaking lines
Southland		N/A	SH93 (13.1 km)	None

For some regions the maintenance records did not clearly show when and where increased reflective roadmarkings have been used irrespective of contract specification changes. For these regions an estimated percentage of the state highway that had increased reflective roadmarking throughout the crash history is shown. These estimates were not used to determine exclusions.

3. Analysis

The analysis uses non-intersection (mid-block) state highway injury-causing crashes that occur in the ‘before’ and ‘after’ periods shown in Table 2.1. The frequency of these crashes is shown in Table 3.1.

Table 3.1 Crashes by region according to before/after contract periods.

Region	Before	After	Total
Northland	395	238	633
Coromandel	118	58	176
Hauraki/Matamata	213	92	305
West Waikato	509	289	798
East Wanganui	452	152	604
West Wanganui	484	217	701
Selwyn/Banks	134	43	177
Central Otago	113	78	191
Coastal Otago	247	226	473
Southland	185	101	286
Total	**2850**	**1494**	**4344**

Although the number of crashes shown in the ‘after’ period is much less than the ‘before’ period, the period time-frames are also significantly less, and the difference in frequency in the ‘before’ and ‘after’ periods needs to be compensated for. Three approaches were used:

- change in average number of crashes,
- change in the ratio of day to night crashes, and
- change in the ratio of crashes on straight sections of road versus crashes on curves.

3.1 Average number of crashes

Any effect of brighter roadmarkings should be shown by change in the average number of crashes on state highways between the ‘before’ and ‘after’ periods. The average number of crashes per year for each region is shown in Table 3.2.

This table shows that the average numbers of crashes per year have increased for five of the regions considered, and decreased for the other five. Otago and Southland appear anomalous because the increase is by between two and three times. Practitioners advise that they are aware of recent efforts in the region to improve reporting rates, and this would impact on the ‘before’ and ‘after’ reported crash numbers. At this coarse level any effect of the change in marking brightness is not obvious.

Table 3.2 Average crashes per year by region by before/after contract period.

Region	Before	After	Total
Northland	132	124	256
Coromandel	39	28	67
Hauraki/Matamata	71	85	156
West Waikato	170	139	309
East Wanganui	151	152	303
West Wanganui	161	154	315
Selwyn/Banks	45	37	82
Central Otago	38	67	105
Coastal Otago	82	246	328
Southland	62	110	172
Total	**951**	**1142**	**2093**

By grouping crashes based on time of day, road type, and road features, the effect might be better seen. The groups used are:

- urban or rural,
- day or night, and
- street lighting or no street lighting.

Rural crashes are those occurring on roads with speed limits greater than or equal to 70 km/h, whereas urban crashes are those occurring on roads with speed limits less than 70 km/h.

Classifying the crashes by day or night requires some consolidation of the data. At the scene of the crash police record the light conditions into one of the following:

- B – bright,
- D – dark,
- O – overcast,
- T – twilight.

In the LTSA crash database the ‘dark_light’ variable combines bright and overcast into ‘light’, and twilight and dark into ‘dark’. ‘Light’ and ‘dark’ correspond to day and night crashes respectively.

In this report we have followed this classifying approach in the first part of the analysis so as to fit the conventional division. However in the second part of the analysis, T - twilight was grouped with B - bright and O - overcast, because in each of these light conditions the roadmarking visibility is determined more by the diffuse twilight lighting than it is by retroreflected light.

Table 3.2 Average crashes per year by region by before / after contract period, urban / rural, street lighting, day / night.

Transit NZ region	Rural					
	No street lighting				Street lighting	
	Day		Night		Night	
	Before	After	Before	After	Before	After
Northland	76	64	35	39	1	1
Coromandel	24	19	7	3	0	0
Hauraki/Matamata	36	50	23	24	1	2
West Waikato	86	74	35	26	13	11
East Wanganui	81	77	44	56	3	0
West Wanganui	86	73	47	44	2	2
Selwyn/Banks Peninsula	27	27	11	8	2	1
Central Otago	24	42	11	18	1	2
Coastal Otago	42	108	23	69	5	7
Southland	35	51	14	35	2	2
Transit NZ region	**Urban**					
	No street lighting				Street lighting	
	Day		Night		Night	
	Before	After	Before	After	Before	After
Northland	13	13	3	5	4	4
Coromandel	5	5	1	0	2	1
Hauraki/Matamata	7	6	2	2	2	2
West Waikato	27	16	3	2	6	8
East Wanganui	16	12	2	3	4	4
West Wanganui	17	29	1	3	8	3
Selwyn/Banks Peninsula	4	2	0	0	1	0
Central Otago	1	5	0	0	1	0
Coastal Otago	9	57	0	1	4	5
Southland	6	15	1	1	4	5

Crashes on roads with street lighting are defined by a variable in the LTSA crash database called ‘st_light’ which has values ‘on’, ‘off’, or ‘none’. A road is street lit when this variable equals ‘on’; for all other values the road is not street lit. Of these values 43% are missing, and of these missing values, 99.3% occur when the crash occurs in light conditions, as described by the ‘dark_–light’ variable. Therefore it is safe to assume that when ‘st_light’ has a missing value, street lighting if present, would not be switched on.

Table 3.3 describes the yearly average frequency of crashes aggregated by these groups.

In Table 3.3 the average number of crashes per year are shown to have increased for five of the regions considered, and decreased for the other five. Otago and Southland appear anomalous because the increase is by between two and three times. Practitioners there advise that they are aware of recent efforts in the region to improve reporting rates, and this would impact on the before and after reported crash numbers. At this coarse level any effect of the change in marking brightness cannot be seen. The difference between the average number of crashes in the 'before' and 'after' period can also be seen in Table 3.3. The differences vary markedly between regions, giving no overall trend.

3.2 Crashes during light and dark conditions

Comparing the ratios of day to night crashes helps to reduce effects arising from moderate changes in traffic volume over the time of this study, as it does also for the split in traffic travelling at night compared to the day for the different sites. Due to the low number of crashes in many groups, comparisons are valid for only the 'rural, no street lighting' group.

The first comparison is to compare totals for all treated regions.

The hypothesis is that bright roadmarkings should have little impact on crashes in daylight, but should reduce night-time crashes. The situation can be expressed as a matrix of day and night crashes, and 'before' and 'after':

Period **Time**	Before	After
Night	*x*	*a*
Day	*y*	*b*

If the intervention has been successful, then

$$a < \frac{x \times b}{y}$$

And, if unsuccessful, then

$$a < \frac{x \times b}{y}$$

The matrix for all regions considered is:

Period **Time**	Before	After
Night	*250*	*a*
Day	*517*	*585*

The night rate ‘after’, *a*, is 322 crashes in total which implies that the intervention has not been successful. If the ‘after’ condition was no better than ‘before’, then the night-time ‘after’ crashes, *a*, in the same proportion as the daylight crashes, should have totalled 283.

To identify whether one or two particular regions were hiding a trend in most regions, a regional comparison was undertaken and is shown in Table 3.3. The table shows the ratio of crashes in daylight to night-time crashes (that is, the number of daylight crashes divided by the number of night-time crashes).

Table 3.3 Ratios of day to night crashes.

Region	Rural	
	No street lighting	
	Before	After
Northland	2.14	1.65
Coromandel	3.23	6.50
Hauraki/Matamata	1.59	2.08
West Waikato	2.49	2.85
East Wanganui	1.83	1.38
West Wanganui	1.83	1.66
Selwyn/Banks Peninsula	2.35	3.44
Central Otago	2.09	2.33
Coastal Otago	1.83	1.57
Southland	2.42	1.47

An increase in the ratio of day to night crashes indicates that either:

- the number of day crashes has increased relative to the number of night crashes – a result that should have little connection to an increase in roadmarking brightness, or
- the number of night crashes has decreased relative to the number of day crashes – a result indicative of a safety benefit for brighter roadmarkings.

Table 3.4 shows that five out of ten regions record a reduction in the ratio of day crashes/night crashes, when comparing the ‘after’ situation to the ‘before’ situation, indicating no particular trend.

Table 3.5 effectively combines the previous two tables and shows the coincidence of the day crashes decreasing with the day/night ratio of crashes increasing. This indicates that it is the night crash rate that is decreasing, which implies that the brighter roadmarkings have been effective in reducing crash rates.

Table 3.5 Summary of brighter roadmarkings effects on day/night crash ratio, by region.

Transit NZ region	Day crashes decrease	Day/night ratio increase	Indication that markings are effective
Northland	Yes	No	No
Coromandel	Yes	Yes	Yes
Hauraki/Matamata	No	Yes	N/A
West Waikato	Yes	Yes	Yes
East Wanganui	Yes	No	No
West Wanganui	Yes	No	No
Selwyn/Banks Peninsula	Equal	Yes	Yes
Central Otago	No	Yes	N/A
Coastal Otago	No	No	N/A
Southland	No	No	N/A

Table 3.5 shows that of the ten regions, only six have a decreasing number of day crashes on the rural, unlit highway section. Of those six regions, three have an increasing day/night crash ratio and therefore support the hypothesis that brighter roadmarkings have reduced night crashes. However, the other three regions have a decreasing day/night crash ratio which indicates no effect. This is insufficient for any certainty of a beneficial effect arising from increasing roadmarking brightness.

3.3 Comparison of treated regions with other roads

A comparison of crash rates on open roads within the treated regions with crash rates on all open roads and on all state highway open roads was made. This gives context to the crash rates on the treated regions. It could be that an apparent null result is actually positive when compared to crash trends on other roads.

In Tables 3.6, 3.7 and 3.8 the April 1997 to April 2000 period is similar to the 'before' period for the treated regions; April 2000 to April 2002 corresponds to the implement-ation period; and April 2002 to April 2004 corresponds to the 'after' period. The tables show crashes in light and dark conditions, and the light/dark ratio with first T - twilight included with D – dark, then second, with T – twilight included with B - bright and O – overcast.

Table 3.6 is for all mid-block crashes on open roads, i.e. all rural roads with a speed limit greater than 70 km/h. Table 3.7 is the similar crash data for all state highways. Table 3.8 is the crash data for only those crashes most likely to be associated with delineation, that is with movement types considered as 'head-on' type crashes on bends or 'cornering' type crashes on bends. All three tables show crash trends for the same years April 1997 to April 2004. As this part of the analysis was undertaken in June 2005, the opportunity was taken to include the April 2003-2004 year.

Table 3.6 Crashes on open roads (intersections excluded), during the light and the dark.

Period	T with D			T with B and O			Total
	B,O	T,D	B,O / T,D	B,O,T	D	B,O,T / D	
Apr97-Apr98	1,905	1,030	1.85	2,046	889	2.30	**2,935**
Apr98-Apr99	1,854	1,030	1.80	2,002	882	2.27	**2,884**
Apr99-Apr00	1,897	1,014	1.87	2,045	866	2.36	**2,911**
Apr00-Apr01	1,681	970	1.73	1,806	845	2.14	**2,651**
Apr01-Apr02	2,140	1,155	1.85	2,294	1,001	2.29	**3,295**
Apr02-Apr03	2,135	1,195	1.79	2,288	1,042	2.20	**3,330**
Apr03-Apr04	2,482	1,431	1.73	2,682	1,231	2.18	**3,913**
Total	**14,094**	**7,825**		**15,163**	**6,756**		**21,919**

B = bright sun, O = overcast, T = twilight, D = dark

Table 3.7 Crashes on open state highways roads (intersections excluded), during the light and the dark.

Period	T with D			T with B and O			Total
	B,O	T,D	B,O / T,D	B,O,T	D	B,O,T / D	
Apr97-Apr98	1,257	643	1.95	1,335	565	2.36	**1,900**
Apr98-Apr99	1,192	669	1.78	1,281	580	2.21	**1,861**
Apr99-Apr00	1,272	643	1.98	1,363	552	2.47	**1,915**
Apr00-Apr01	1,099	634	1.73	1,185	548	2.16	**1,733**
Apr01-Apr02	1,370	717	1.91	1,473	614	2.40	**2,087**
Apr02-Apr03	1,315	741	1.77	1,412	644	2.19	**2,056**
Apr03-Apr04	1,569	854	1.84	1,682	741	2.27	**2,423**
Total	**9,074**	**4,901**		**9,731**	**4,244**		**13,975**

B = bright sun, O = overcast, T = twilight, D = dark

Table 3.8 Crashes on open roads (intersections excluded) more likely to be related to delineation, during the light and the dark.

Period	T with D			T with B and O			Total
	B,O	T,D	B,O / T,D	B,O,T	D	B,O,T / D	
Apr97-Apr98	982	555	1.77	1,070	467	2.29	**1,537**
Apr98-Apr99	984	524	1.88	1,060	448	2.37	**1,508**
Apr99-Apr00	913	542	1.68	1,000	455	2.20	**1,455**
Apr00-Apr01	866	537	1.61	931	472	1.97	**1,403**
Apr01-Apr02	1,052	599	1.76	1,132	519	2.18	**1,651**
Apr02-Apr03	1,117	637	1.75	1,194	560	2.13	**1,754**
Apr03-Apr04	1,234	766	1.61	1,328	672	1.98	**2,000**
Total	**7,148**	**4,160**		**7,715**	**3,593**		**11,308**

B = bright sun, O = overcast, T = twilight, D = dark

The data does give one area for concern in that a marked drop is apparent in crashes in the April 2000-2001 year, but which rebounds immediately in the April 2001-2002 year, and to a rate substantially higher than in the years from 1997 to 2000. This trend is consistent across all three tables.

Usually this data trend would be thought to indicate irregularities around reporting, but when examining the ratio of crashes in the day to crashes at night it is noticeable that the2000-2001 year is the period of lowest total crashes, and is also the period of the lowest day/night crash ratio. Usually it would be expected that any under-reporting would affect both day-time and night-time crashes evenly.

The series of Figures 3.1 to 3.4 show that the trend found for the treated state highways is mirrored almost exactly by these comparable roads and datasets. This again points to the brighter roadmarkings having little impact on crash rates.

Figures 3.1 to 3.4 show the type of data in Tables 3.6 to 3.8 in graphical form. Each of the figures shows the ratio of the number of crashes in light conditions to the number of crashes in dark conditions.

- Figure 3.1 shows data for just the open roads upon which brighter roadmarkings have been provided. This represents the smallest dataset and the one which when compared with the other figures and datasets, should illustrate any effects of the brighter roadmarkings.

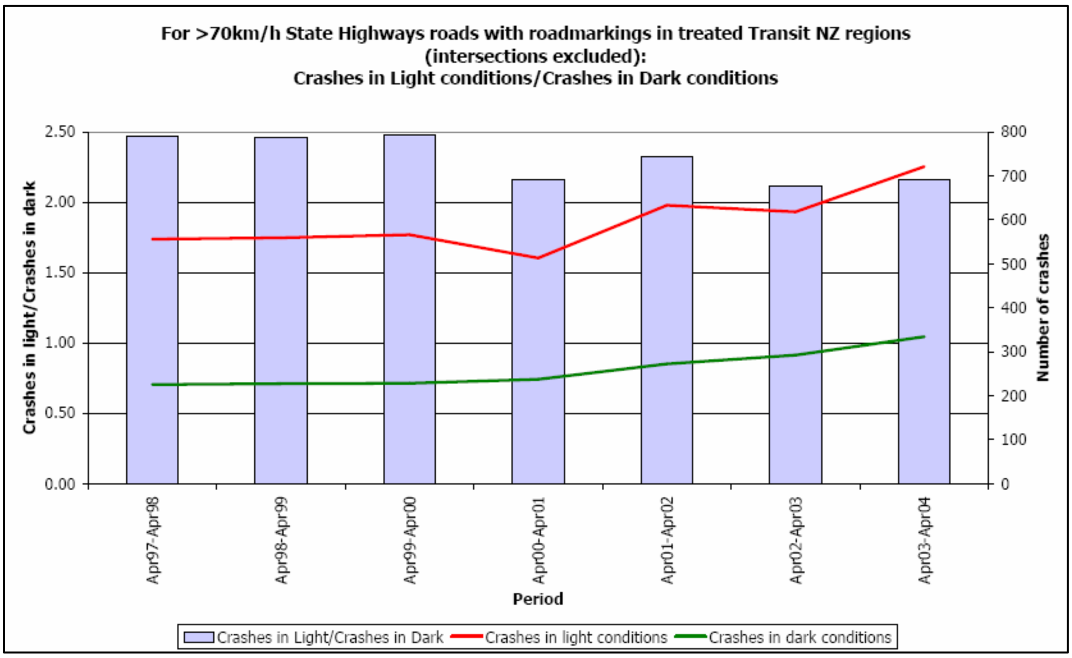

Figure 3.1 Ratio of crashes in light conditions to dark conditions for open state highway roads (intersections excluded) in treated areas.

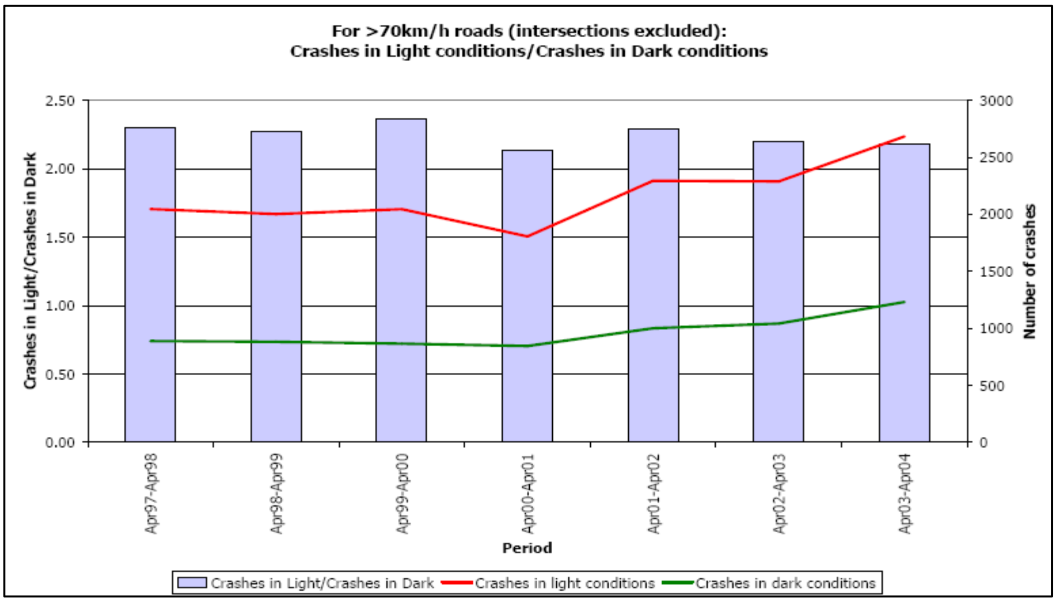

Figure 3.2 Ratio of crashes in light conditions/crashes in dark conditions for open roads (intersections excluded).

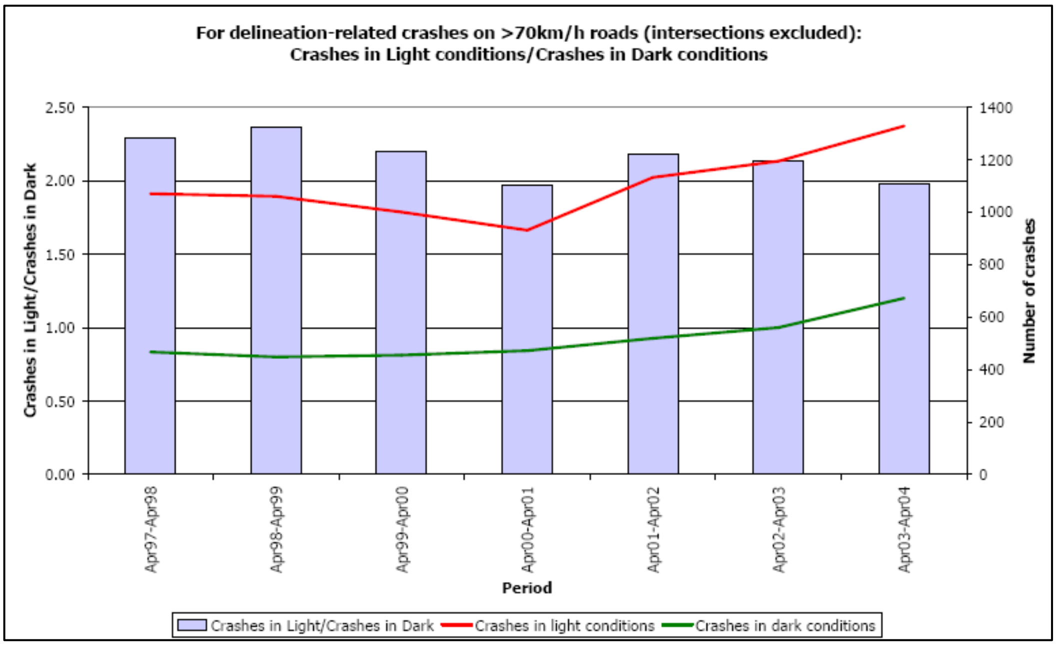

Figure 3.3 Crashes in light conditions/crashes in dark conditions for open roads (intersections excluded), for crashes more likely to be related to delineation.

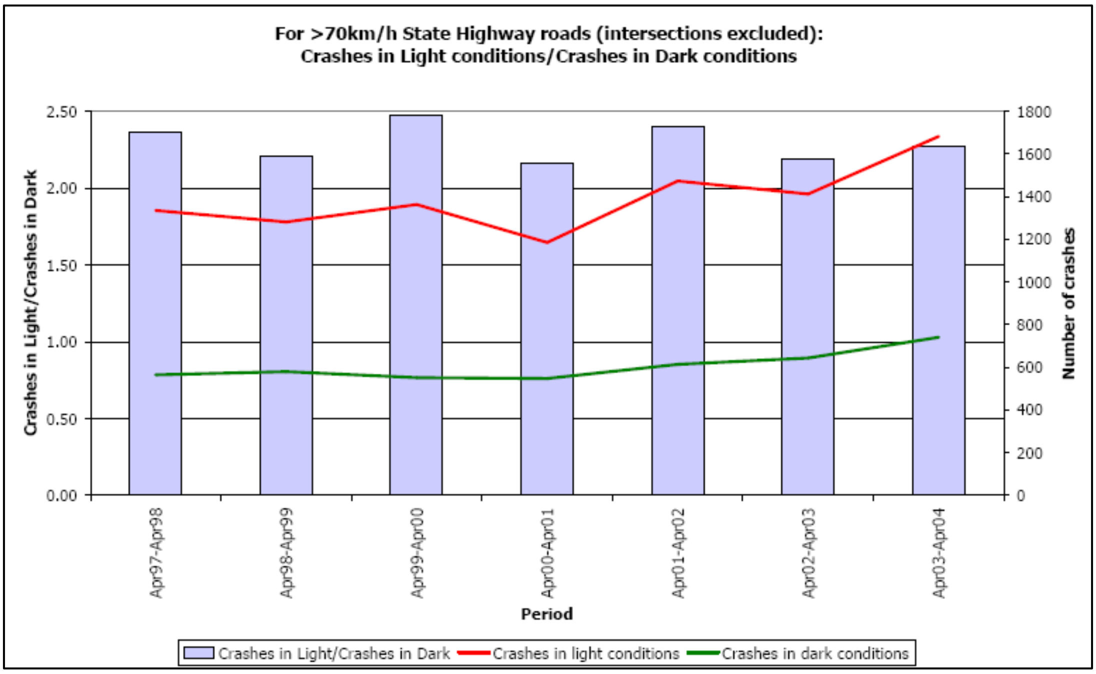

Figure 3.4 Crashes in light conditions/crashes in dark conditions for all open treated and untreated state highway roads (intersections excluded.

- Figure 3.2 shows data for all open roads in New Zealand. This represents the largest dataset and identifies trends that may be background to the brighter roadmarkings study period.
- Figure 3.3 shows data for all open roads in New Zealand but just for those crash types that are more likely to be affected by delineation.
- Like Figure 3.1, Figure 3.4 shows data for newly open state highway roads, all of which are considered to have full delineation provided. Figure 3.1 shows only the data for state highways in the treated regions.
- Figure 3.4 differs in that it shows the data for all state highways, treated and untreated.

3.4 Crashes on curves or straights during the daylight or dark

Another analytical approach is to examine ratios of crashes on curves and straights, by day and by night.

The theoretical basis for this type of analysis is the commonly-held belief (supported by the research discussed in the executive summary) that delineation has a particular role in assisting safe driving around curves at night-time. This belief is expressed in practices such as:

- A more dense use of edge marker posts and edge marker reflectors on curves compared to straights;
- The use of chevron boards, and painted railings to help show the curve at night;
- The use of roadmarkings on curves, but not on straights, such as on some low-volume roads in remote areas.

The rationale is that improving the delineation on the curves should help to provide night-time drivers with a similar sense of the road geometry as is provided by daylight.

In the context of this current project, the use of brighter roadmarkings should have helped to increase the visibility of the curve, and the benefit of the improvement would be demonstrated by a relative reduction in crashes on those curves.

Comparing the ratio of crashes on straights and curves normalises for traffic volume, weather conditions, and driver attributes since each driver making a particular journey needs to successfully negotiate each straight and curve along the route.

The essential hypothesis is that if drivers could be provided with an equivalent rich visual field at night-time as they have under daylight conditions, then safety would improve. Under this hypothesis, the analysis is based on a matrix:

Light Condition **Road Geometry**	Light	Dark
Curve	*a*	*c*
Straight	*b*	*d*

The ratio of crashes on curves to crashes on straights is *a*:*b* for light conditions, and *c:d* for dark. Ratio *a:b* should therefore represent the relative rate of crashes on curves:straights under optimum lighting/delineation conditions. Ratio *c:d* should be significantly greater than *a:b* on poorly delineated roads, and reduce as delineation is improved.

Three data extracts were made from the CAS database. The first, for all open roads, intersections excluded; the second, for those state highway open roads where roadmarking brightness had been increased; and the third data extract was for all state highways.

Figures 3.5, 3.6, and 3.7 show the analysis. While in this analysis crashes are grouped by year, rather than by ‘before’ and ‘after’, the match is quite good:

- The time period April 1997 to April 2000 represents most of the ‘before’ period.

- April 2000 to April 2002 is both the transition period in which the improvement was made and also a time when the data does not appear reliable (as discussed earlier, Section 3.3 p.30).
- April 2002 to April 2004 is the 'after' period.

(Because this analysis has been undertaken ten months later than the work discussed in Sections 3.1 to 3.3, the opportunity to include valid data from the April 2003 to April 2004 year has been taken.)

Figure 3.5 is for all open roads, and so will include many lower volume rural roads where the level of delineation is a very low. In contrast, most of the state highways will have substantial delineation, including centre and edge lines, edge marker posts, RRPMs, and chevron boards.

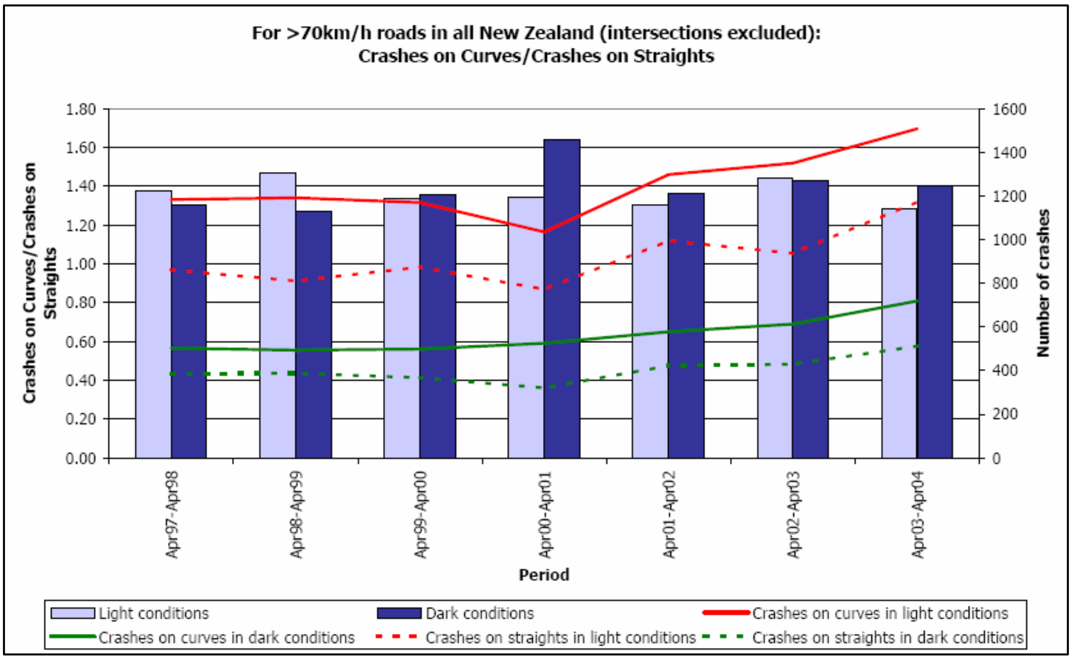

Figure 3.5 Crashes on curves/crashes on straights for open roads (intersections excluded) in treated areas.

Figure 3.6 shows the analysis for open road state highways where the bright roadmarkings have been installed.

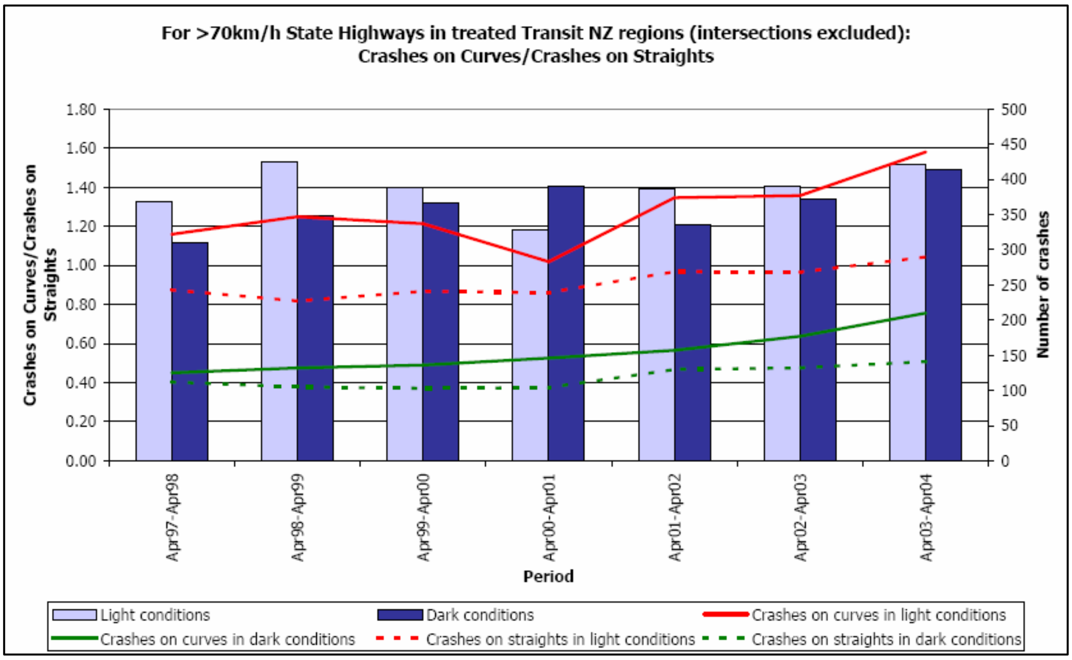

Figure 3.6 Crashes on curves/crashes on straights for open road state highways (intersections excluded) in treated areas.

Figure 3.7 is for all state highways throughout New Zealand, treated and untreated.

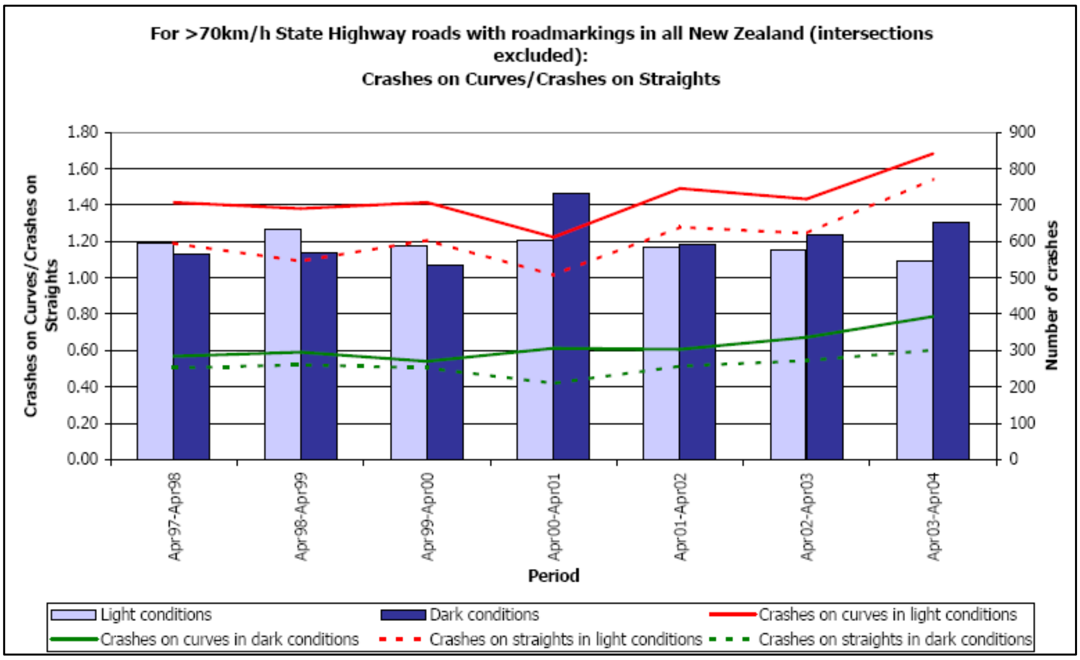

Figure 3.7 Crashes on curves/crashes on straights for open road state highways (intersections excluded).

Comparing the 'before' and 'after' periods (excluding the installation periods) and comparing first all open roads (Figure 3.5) and second all state highway open roads (Figure 3.7) with the improved state highway open roads (Figure 3.6), shows no noticeable change caused by the brighter roadmarkings. This finding, though unexpected, is explained by the same discussion given previously, that of drivers' adaptive behaviour.

All these graphs, Figures 3.5 to 3.7, show a rising crash rate across the time period for both straights and curves during light conditions and dark conditions. Far more importantly however is that the ratio of crashes on curves to crashes on straights is very nearly the same for dark compared to light conditions.

Figure 3.8 presents Figure 3.6 in a modified way. This plots the ratio of crashes on curves in light conditions versus crashes on curves in dark conditions, and similarly, the ratio of crashes on straights in light conditions versus crashes on straights in dark conditions, for the improved state highway open roads. A fall-off of the incidence of crashes on curves (relative to the incidence of crashes on straights) from the brighter roadmarkings should result in the ratio increasing.

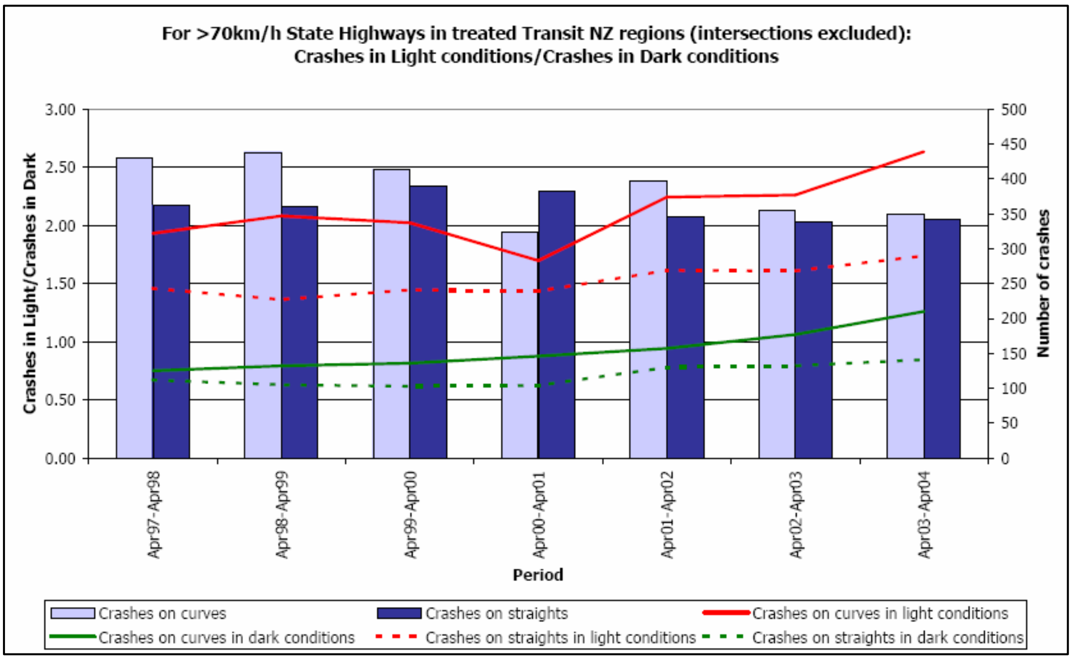

Figure 3.8 Crashes in light conditions/crashes in dark conditions for open state highway roads (intersections excluded) in treated areas.

Figure 3.8 shows a small trend for the ratio to actually decrease indicating the crashes in the dark on curves are increasing at a faster rate than crashes in the light on curves. The crash ratio on straights shows an equivalent but smaller decrease, and again it can be seen that crashes in the dark are increasing at a rate faster than for crashes in the light.

It could be argued that the brighter roadmarkings had no effect because delineation was already bright enough. When combined with the RRPMs and the edge marker posts, the bright roadmarkings may have had no visual effect and consequently no safety effect.

To evaluate this possibility, a fourth extract was made from the CAS, this time of mid-block injury-causing crashes on open roads with no street lighting and traffic volumes less than 250 vehicles per day. These will generally be unmarked, without RRPMs, and many will have only isolated use of edge marker posts.

Figure 3.9 shows the data, again expressed as a ratio of crashes on curves versus straight, for light and dark conditions.

Compared to the state highways, the ratios for both light and dark conditions are higher, indicating a greater hazard on curves on these rural roads, but this could be expected given their often poor geometry.

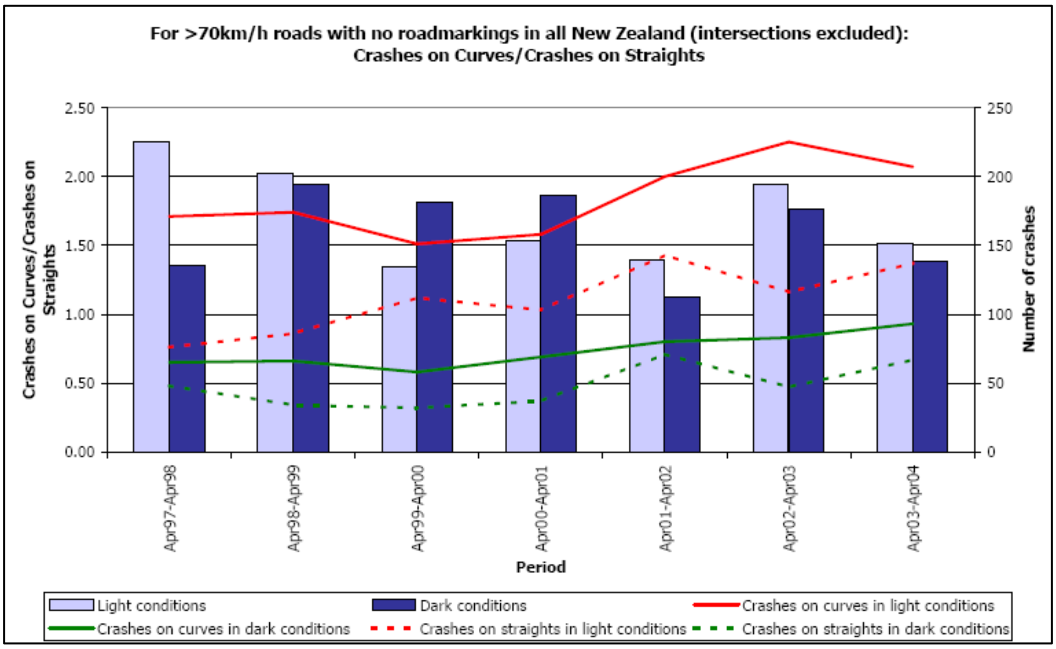

Figure 3.9 Crashes on curves/crashes on straights for open roads (intersections excluded) with no roadmarkings.

Given the very large change in the richness of the visual field in daylight, the far greater visibility distance in light, and the absence of night-time delineation on most of these roads, a substantial difference in crash rates, day compared to night, could have been expected. The absence of a significant difference could arise from several factors, one being that the basic hypothesis is wrong.

However, it is more likely that drivers using low volume rural roads at night which have little delineation are aware of the potential hazard of poor visibility and adjust their behaviour accordingly. Such a finding is quite compatible with a number of driving task models, such as that of Ogden (1996), or the theory of role homeostasis, for instance. These models hypothesise that drivers drive to an almost constant loading of risk. As driving conditions become easier, the driver adds additional tasks, and conversely discards unnecessary tasks when conditions become more difficult.

4. Conclusions

A study has been undertaken to establish the safety benefit of installing brighter roadmarkings on New Zealand state highway open roads. The study involved comparing frequencies of crashes before and after the implementation of new Transit New Zealand regional contracts, which specified increased reflective roadmarking. Comparisons of trends against trends on rural roads and trends on all (treated and untreated) state highways were also made. Comparisons were completed several ways: annual average crash frequency, ratio of light to dark crashes, and crashes on curves compared to straights. In all the methods no significant trend of brighter roadmarkings having an effect on reducing crash rates could be isolated.

This null finding needs to be viewed within the context of:

- The crash data not being large.
- The improvement being made to only roadmarkings, when other elements such as RRPMs and edge marker posts were present.
- The increase in marking brightness being only moderate compared to what might have been possible from using the best available materials.
- The data is contradictory in that some regions indicated improved safety while others indicated worsening safety. This contradictory finding could reflect changes in crash reporting over time for some regions.

Overall it appears that identifying benefits of improving one or only several of the total number of elements that provide delineation by means of a before and after study of crashes will often be inconclusive and perhaps unreliable.

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