The effect of better road delineation: a new method of assessment

April 2011

D Walton, JA Thomas, SJ Murray and M Fourie
Opus Central Laboratories, Wellington

NZ Transport Agency research report 442

ISBN 978-0-478-37189-5 (print)
ISBN 978-0-478-37190-1 (electronic)
ISSN 1173-3756 (print)
ISSN 1173-3764 (electronic)

NZ Transport Agency
Private Bag 6995, Wellington 6141, New Zealand
Telephone 64 4 894 5400; facsimile 64 4 894 6100
research@nzta.govt.nz
www.nzta.govt.nz

Walton, D, JA Thomas, SJ Murray and M Fourie (2011) The effect of better road delineation: a new method of assessment. *NZ Transport Agency research report 442*. 66pp.

Keywords: New Zealand, risk perception, road delineation, safety, self-explaining roads

An important note for the reader

The NZ Transport Agency is a Crown entity established under the Land Transport Management Act 2003. The objective of the Agency is to undertake its functions in a way that contributes to an affordable, integrated, safe, responsive and sustainable land transport system. Each year, the NZ Transport Agency funds innovative and relevant research that contributes to this objective.

The views expressed in research reports are the outcomes of the independent research, and should not be regarded as being the opinion or responsibility of the NZ Transport Agency. The material contained in the reports should not be construed in any way as policy adopted by the NZ Transport Agency or indeed any agency of the NZ Government. The reports may, however, be used by NZ Government agencies as a reference in the development of policy.

While research reports are believed to be correct at the time of their preparation, the NZ Transport Agency and agents involved in their preparation and publication do not accept any liability for use of the research. People using the research, whether directly or indirectly, should apply and rely on their own skill and judgement. They should not rely on the contents of the research reports in isolation from other sources of advice and information. If necessary, they should seek appropriate legal or other expert advice.

Acknowledgements

The authors would like to acknowledge the support of the Greater Wellington Regional Council and Hutt City Council.

Abbreviations

COST	European Co-operation in the Field of Scientific and Technical Research
M	Mean
MCP	Microchannel Plate
N	Total number in the sample
n	Total number in the subsample
Rl	A measure of retroreflectivity
SD	Standard Deviation
SUV	Sports utility vehicle
t	Studentised t value
TIRTL	Infrared Traffic Logger

Contents

Executive summary

Increasing the visibility of the road ahead decreases the likelihood of drivers losing control of their vehicle and either crossing the centre line or running off the road. New technologies have resulted in new products that increase the retroreflective brightness of roadmarkings. New Zealand-based research has attempted to quantify the associated benefits of brighter roadmarkings as a reduction in crash likelihood, but without real success. As the context of any epidemiological investigation is obscured by the many other influences on crash rates, isolating the effect of roadmarkings has been elusive, especially in New Zealand where we have relatively small volumes of traffic. Overseas attempts to quantify the crash-reduction benefits of roadmarkings have also been inconclusive. Consequently, minimum standards for retroreflectivity (ie the level of brightness reflected back from car headlights) vary widely (between 90 and 130Rl).

In road safety science, 'intermediate outcome' measures are used as a proxy measure for drivers' crash risk or actual crash rates. These include vehicle speed, headway, seatbelt use, lane position and gap acceptance. In this research, the usual intermediate outcomes were used to assess the effect of improved road delineation on driver behaviour. In addition a new, innovative, intermediate outcome measure, called the 'hands-on' method (Walton and Thomas 2005), was used in an attempt to determine an evidence-based standard for minimum roadmarking retroreflectivity in New Zealand. The method uses hand positions on the steering wheel as an indicator of drivers' perceived risk, with drivers being more likely to place both their hands on the top half of the steering wheel when driving through a more difficult environment. The 'hands-on' method was selected as an indirect measure of perceived risk that is sensitive to changes in the driver's visual environment. This method was tested to see if it could be used to measure the effect of improvements in roadmarkings immediately after an upgrade (a more immediate measure than crash studies).

The hand-position configurations, as well as other intermediate measures of driver safety (speed and headway acceptance), of 2896 drivers were observed at three sites in the Greater Wellington region in 2009–2010, in order to examine changes in drivers' risk perceptions due to variations in road visibility. Within each site, comparisons were made between:

- daytime (well-lit) and night-time (dark) conditions
- wet and dry conditions
- faded roadmarkings and brighter roadmarkings (before and after delineation interventions).

The key premise behind the 'hands-on' method was that dry daytime conditions offered visibility conditions that were essentially 'ideal'. Any detectable difference in drivers' behaviour (speed, headway or hand positions) from the baseline dry daytime condition would be indicative of a change in drivers' perceived risk – and the size of the reaction would be a direct measure of the effect of the changed delineation relative to baseline conditions.

The initial findings found no detectable difference in hand-position configurations between night-time and daytime conditions across all three sites, despite wide variation in the quality and performance of the roadmarkings. A closer examination of the driver characteristics showed that a drop-off in older drivers at night was likely to be responsible for the lack of a detectable difference in the pattern of hand positions at night, as older drivers are typically more cautious. Thus, any additional caution in drivers at night was balanced by the fact that there was a reduction in the number of drivers with a cautious driving style.

The research found that an improvement in road delineation created conditions that were comparable to daytime driving conditions, and this means that it is possible to create an improved visual environment at night without the expense of lighting solutions (ie streetlights). After the delineation intervention that we studied, which improved the retroreflectivity of the roadmarkings from 38Rl to 142Rl, night-time drivers were about twice as likely to adopt a steering wheel hand-position configuration similar to daylight conditions (ie a more relaxed hand position). About 11% of drivers changed from the cautious hand position of having two hands on the top half of the steering wheel, which was a relative shift of 37% of the drivers who would have originally adopted this cautious hand position.

Wet conditions elicited the highest level of perceived risk, with 53% of drivers adopting a '10 to 2' (on an analogue clock face) hand position – this was the highest recorded proportion of drivers with this hand position to date across any of the previous studies of hand positions. When compared with dry daytime or dry night-time conditions at the same site, drivers were 2–2.5 times more likely to adopt a '10 to 2' hand position in wet conditions. Drivers also adjusted their speed to about 9kph slower in the wet conditions.

The evidence from this study revealed a successfully tested method to quantify the benefits of improved retroreflectivity in roadmarkings. The 'hands-on' measure was more sensitive than speed or headway in quantifying delineation improvements, and indicated driver performance issues prior to driver error (such as failure to maintain the vehicle within the traffic lane). Thus, the retroreflectivity performance of roadmarkings can be assessed against whether they replicate a night-time visual environment that is as good as the dry daytime visual environment, as indicated by the degree to which drivers return to the more relaxed hand-position configuration that they exhibit when driving in the daytime.

Recommendations:

1. Delineation solutions for wet conditions should be given more priority than solutions for night-time conditions, because wet conditions create the most difficult driving environment. This recommendation is based on the evidence that even in the daytime, drivers were 2.5 times more likely to place two hands on the top half of the steering wheel when it was raining, compared with night-time conditions. The extent of the opportunity to offset the observed effect with improved delineation was not fully determined here, and some component of the effect may have been because of drivers' response to a change in their perceived risk due to changes in the surface conditions, rather than to changes in the quality of their visual field for driving.

2. The relationship between retroreflectivity and hand positions can now be modelled, using multiple sites with different increments in retroreflectivity, to determine the relationship between improvement in retroreflectivity and its effect on drivers.

3. Before/after assessments of engineering interventions to improve the road corridor can include observations of intermediate measures such as hand position to determine the effects of changes on drivers. As the 'hands-on' method is a more sensitive tool than speed or headway, it should be used as a measure of subtle changes in drivers' perceived risk.

4. The 'hands-on' method measured an unexpected but very significant reduction in night-time driving by older people, which needed to be controlled for, and should be investigated separately. It was beyond the scope of this research to determine the extent to which effective road delineation could affect general driving behaviour in a specific sector of the community. However, further research could examine the improved social/travel opportunity outcomes for older drivers that would result from an improved night-time driving environment.

Abstract

In this research project, the innovative 'hands-on' method, first developed by Walton and Thomas in 2005, was tested in its ability to evaluate the effects of improved road delineation on driver behaviour. The method uses hand positions on the steering wheel as an indicator of drivers' perceived risk, with drivers being more likely to place both their hands on the top half of the steering wheel when driving through a more difficult environment.

Specialist night-vision equipment and infrared floodlights were used to observe a total sample of 2896 drivers at three sites in the Greater Wellington region in 2009–2010. Other intermediate measures of perceived risk (speed and headway acceptance) were also recorded, in order to assess how drivers' risk perceptions changed with variation in the driving conditions (daytime/night-time, wet/dry) and road delineation (faded/upgraded roadmarkings).

The results showed that the 'hands-on' method was an effective and reliable tool to measure the impact of improved linemarkings on drivers, and to quantify the size of this effect compared with daylight driving. The method was sensitive to subtle changes in the road context, which makes it a useful instrument for road engineers to evaluate the relative improvement or change in drivers' responses to changes in road contexts.

1 Introduction

Increasing the visibility of the road ahead decreases the likelihood of drivers losing control of their vehicle and either crossing the centre line or running off the road. Following recent efforts to increase the brightness of roadmarkings in New Zealand, a number of studies have attempted to quantify the associated reduction in the likelihood of a crash, but with limited success.

This research project, which was conducted between 2008 and 2010, aimed to trial a new method of observing drivers' reactions to the roading context, in order to establish the effect of improved road delineation on driving behaviour.

The visibility of roadmarkings is a key factor in maintaining lane position while driving. The importance of bright roadmarkings is particularly apparent when driving in reduced-visibility conditions, such as when driving at night, or in wet weather (Konstantopoulos et al 2010). The incidence of road accidents is estimated to increase by 40% at night (Johansson et al 2009) and by 70% in wet weather conditions (Andrey and Yagar 1993).

Drivers rely on roadmarkings to provide a short-range view for lane-keeping, and a longer-range view of upcoming changes in the road geometry. Land and Lee (1994) showed that successful horizontal curve negotiation relies on previewing upcoming curves about 1–2 seconds in advance. In 1999, European research used driving simulator experiments to examine the minimum threshold of sight distance of the road ahead that was required to navigate successfully (European Co-operation in the Field of Scientific and Technical Research 1999). They found that drivers adapted to sight distances of 1.8–2.7 seconds by reducing their speed and the variation in their lateral position on the road. Drivers began to fail to navigate horizontal curves when sight distances were 1.2–1.8 seconds. Consequently, they recommended that drivers should be able to preview roadmarkings at an absolute minimum of 1.8 seconds in advance (the equivalent of a 50m sight distance when travelling at 100kph).

Brighter roadmarkings increase the visual field of drivers, but determining best practice regarding the minimum level of brightness is difficult – so far, the relationship between roadmarkings, road accidents and driver performance has been hard to quantify.

1.1 Brightness of roadmarkings

Requirements for the brightness of roadmarkings in New Zealand were established in 1996, and the specifications are outlined in the *Manual of traffic signs and markings* MOTSAM (NZTA 2010) and the *Road and traffic standard 5: guidelines for rural road marking and delineation (RTS-5) (*MoT 1992). The recommended minimum standard in New Zealand is 100Rl (RI is a measure of retroreflectivity[1]), whereas overseas recommendations vary between about 90 and 130Rl (see Debaillon et al 2008). Reflectorised markings increase the visibility of the road ahead and are believed to decrease the likelihood of drivers losing control of their vehicle and running off the road. While increases in the visibility of roadmarkings can be noticed in all light conditions, their biggest impact is when it is dark. However, road controlling authorities do not currently have a reliable method for assessing the effects of brighter roadmarkings.

1 Retroreflectivity is the night-time visibility of the roadmarkings reflected back to the driver by the vehicle's headlights. Retroreflectivity is the common metric used to determine the relative effect of pavement markings on road accidents (Masliah et al 2007).

Until now, the most common method for evaluating the effect of road delineation improvements has been to compare crash rates before and after improvements were made, but the results of previous New Zealand-based evaluations of the effect of brighter roadmarkings have been inconclusive. A 2006 report for Land Transport NZ (Dravitzki et al) compared crash rates before and after improvements in a number of ways, including annual crash averages, the ratio of daylight to night-time crashes, and crashes on curves compared with straights. However, they found no evidence that brighter roadmarkings had a positive effect in reducing crash rates.

In overseas studies (eg Masliah et al 2007), the relationship between roadmarking retroreflectivity and accident risk was also inconclusive. McKnight et al (1998) found that the contrast and width of roadmarkings only influenced lane-keeping performance where the contrast ratio (between the roadmarking and the road surface) was very low. Donnell et al (2009) pointed out that a common problem is that many studies do not take into account the degradation of the pavement markings over time. There are also many factors that may confound the relationship between crash risk and retroreflectivity because of the lack of control in real-world settings. Donnell et al found that road type confounds the relationship between retroreflectivity and crash risk, such that retroreflectivity only reduces crash risk in multi-lane highways.

1.1.1 Roadmarkings and driver performance

Driver performance can also be used as an indicator of roadmarking effectiveness. Speed, headway (to a lead vehicle) and lane position on the road are the most commonly examined driver performance measures. In a meta-analysis across 65 experiments examining the effects of an edgeline on speed and lateral position, van Driel et al (2004) found a large variation in the results. Most of the studies were naturalistic field observations (77%, n = 50), and most involved a before/after method where the same section of road was examined before and after the addition of an edgeline (69%, n = 45). The effects ranged from an *increase* in speed of about 10kph to a *decrease* in speed of about 5kph, and shifts in lane position *towards the edge of the road* of about 35cm to a shift *towards the centre of the road* of about 30cm.

However, edgelines did have a strong influence over driver speed and lateral position (particularly when there was no centre linemarking) where speeds were higher and drivers were therefore likely to drive closer to the centre of the road. Where there was a wider road shoulder and a narrow roadside environment (eg buildings or trees beside the road, as opposed to wide, open fields), drivers moved closer to the edgeline.

Van Driel et al (2004) found that the specific characteristics of the edgeline, including its width (5cm or 10cm), colour (white or yellow) or type (continuous or intermittent) did not have any significant influence on speed or lane position. However, none of the studies examined the before/after effects of a change to an existing edgeline within the same site.

Other possible driver performance measures, such as those examined by Glendon (2007), include tailgating, using a hand-held mobile phone, inappropriate signalling, lane violations, cutting in front of other traffic, and hands position on the steering wheel (see discussion in section 1.2).

1.1.2 Measuring the effect of brighter roadmarkings in experimental conditions

Using an eye-tracker in an instrumented vehicle, Suh et al (2006) found that drivers' behavioural measures (eg vehicle speed, lane position and eye movements) varied between major changes in illumination (ie day versus night). They found that drivers' eye movements were more focused when driving in night-time conditions than in the daytime, where they were more likely to look at non-relevant features (eg scenery). One factor could be that the span of drivers' night vision is naturally narrower because of a limited headlight view. Alternatively, it could be an indicator that the workload is lower during the day, meaning drivers have the spare capacity to look at scenery.

In a driving-simulator experiment examining the safety benefits of enhanced roadmarkings in wet night-driving conditions, Horberry et al (2006) found that better markings reduced driver workload and increased driver confidence and comfort. They also found the improved markings meant that drivers were able to maintain better lane position and better consistency in speed.

However, it is known that the test conditions of using driving simulators or instrumented vehicles change a driver's behaviour – participants may drive more cautiously because they know their performance is being monitored, they are driving an unfamiliar vehicle, and they may be wearing technical equipment. For example, Evans (2004) noted that reaction times were substantially shorter in experiments using instrumented vehicles than in conditions of normal driving. Such improved response times are possibly due to the Hawthorne effect, where performance is artificially increased as a function of a participant knowing that his performance is being measured.

Low participant numbers and higher equipment and data-coding costs make the use of simulators or instrumented vehicles impractical when examining subtle changes in driver behaviour across complex environments. While Horberry et al's experiment (2006) indicated that brighter roadmarkings improved the environment for drivers and increased driver comfort (all their subjects were exposed to the same conditions), the true quantification of the level of effectiveness of brighter roadmarkings could only be validated in a real-world setting.

1.2 The 'hands-on' measure

The 'hands-on' measure was developed by Walton and Thomas in 2005 as a method of naturalistic observation used to evaluate driver responses to variation in real-world roading contexts. The method is observational and uses the following ordinal categorisation to describe the position of a driver's hands on the top half of the steering wheel (as represented in figure 1.1):

- two hands visible between '9 and 3 o'clock' (on an analogue clock face)
- one hand visible between '9 and 3 o'clock' (on an analogue clock face)
- no hands visible between '9 and 3 o'clock' (on an analogue clock face).

Walton and Thomas identified that at an aggregate level (as opposed to individual drivers), drivers altered their hand position as a function of the complexity of the environment – for example, drivers tended to place more hands on the top half of the steering wheel in a 100km/h speed zone than in a 50km/h zone.

The official New Zealand road code (NZTA 2010) recommends that the position of the hands on the steering wheel should be '10 to 2' (as in a clock face). Kline (2001) noted that placing the left hand between '9 and 10 o'clock' on the steering wheel, and the right hand between '2 and 3 o'clock', allowed for balanced shoulder strength. In a study of truck drivers in simulator vehicles, Sanders (1981) showed that when drivers experienced the peak torque of a tyre blowout, 8% of those who placed their hands at '9 and 3 o'clock' lost control of the vehicle, and 16% of those who placed their hands at '1 and 7 o'clock' lost control. However, Walton and Thomas (2005) showed that on average, only 25% of drivers placed two hands on the top half of the steering wheel when driving. Driver hand position changed as a function of the environment and driving context, and it was suggested that when drivers perceived risk in the environment, they responded by looking to gain more control of the vehicle by adjusting their hand position (ibid).

Figure 1.1 An illustration of the ordinal scale of hand positions (Walton and Thomas 2005)

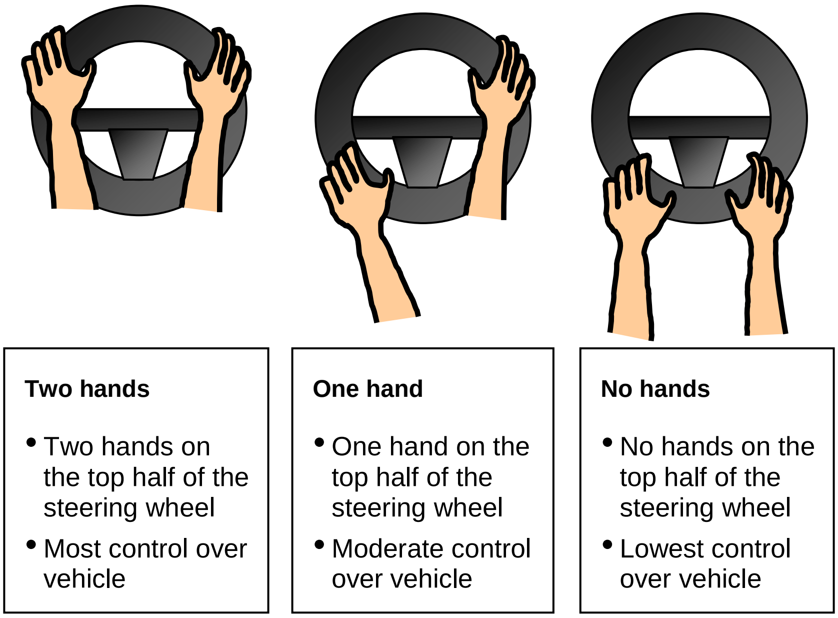


Table 1.1 on the next page outlines the influence on driver hand positions of speed zone, number of traffic lanes (Walton and Thomas 2005), vehicle type (Thomas and Walton 2007), and gender differences (Fourie 2008). Female drivers were 2.87 times more likely than males to drive with two hands (instead of one) on the top half of the steering wheel. Car drivers were 1.55 times more likely than drivers of sports utility vehicles (SUVs) to drive with two hands on the top half of the steering wheel (instead of one) (Fourie 2008, Thomas and Walton 2007). Drivers in a 100kph speed zone were 1.55 times more likely than drivers in a 50kph speed zone to drive with two hands on the top half of the steering wheel instead of one (Walton and Thomas 2005).

Table 1.1 Hand position percentages and adjusted residuals for different driver, vehicle and environmental characteristics, combining the samples of Fourie (2008), Thomas and Walton (2007), Walton and Thomas (2005)

			Number of hands on top half of steering wheel					
			Zero		One		Two	
Characteristic		**N**	**%**	**AR[a]**	**%**	**AR**	**%**	**AR**
Gender	Female	828	17%	-0.2	45%	**-8.3**	38%	**9.6**
	Male	1225	18%	0.2	64%	**8.3**	19%	**-9.6**
	Total	2053						
Vehicle type	Car	578	27%	0.6	49%	**2.3**	24%	**-3.1**
	SUV	618	25%	-0.6	42%	**-2.3**	32%	**3.1**
	Total	1196						
Speed zone	50kph	1161	25%	-0.1	55%	**4.3**	20%	**-4.8**
	100kph	3643	25%	0.1	48%	**-4.3**	27%	**4.8**
	Total	4804						

			Number of hands on top half of steering wheel					
			Zero		One		Two	
Characteristic		N	%	AR[a]	%	AR	%	AR
Lanes	2-lane highway	3214	26%	**4.2**	48%	0.2	26%	**-4.2**
	6-lane motorway	429	17%	**-4.2**	48%	-0.2	36%	**4.2**
	Total	3643						

(a) Adjusted residuals (AR) over 2 indicate a significant finding and are highlighted in bold

By observing the same drivers multiple times in different situations, Walton and Thomas (2005) determined that hand position varied between different driving situations, and such changes were not due to fatigue, driving style or habit. They suggested that this variation in hand position was due to the driver's perception of the risk of the driving environment. It is important to note that while Walton and Thomas (2005) claimed that across samples of drivers, the position of their hands on the steering wheel offered an insight into the risk they perceived (aggregate hand position), they made no claim regarding individual differences that could have influenced driver hand position.

The method used by Walton and Thomas relies on the error being distributed randomly across driving conditions. The measure contains significant error, but so do measures of speed and accident frequency (see Hauer 2002 for a good explanation of error in real-world settings). Therefore, any concern about this aspect should be directed at whether the measure is sensitive enough to detect subtle changes in the road context. For example, they found that hand positions were not sensitive enough to identify a change in driver behaviour in locations signposted as high road-accident zones. This lack of finding was either because the measure was not sensitive enough, or the signs did not influence driver behaviour. The key question is whether analysing hand position can detect differences that are not revealed with other measures such as speed, lane position or headway to a lead vehicle.

Focusing on driver hand position may be a more sensitive method of detecting subtle changes in driver behaviour than speed, lane position or headway, as the latter are exposed to a considerable level of external regulation. Driver speed and lane position are externally monitored and enforced by road safety authorities, and there are insurance consequences for drivers who follow a lead vehicle too closely. There are also social norms around speed selection that are not necessarily applied to hand position (Paris and van den Broucke 2008). Consequently, hand position changes may reflect a less conscious process that is more sensitive to an underlying state of arousal that relates to the driving context.

Thomas and Walton's 2007 study examined the effect of the driving context on driver hand position by studying differences between drivers of vehicles of different sizes. Drivers of large SUVs, who probably felt the safest in their vehicles, were shown to be less likely to adopt the safest hand position in an emergency situation. A follow-up survey of these drivers confirmed that they varied their hand position according to the situation, with two hands on the top half of the steering wheel when they felt tense, and one hand on the top half of the steering wheel when they felt relaxed (see table 1.2). These results combine to suggest that the 'hands-on' method has face validity as a measure of risk perception – a finding that can be explained by transport theories of risk taking, as discussed in the next section.

Table 1.2 Descriptives for self-reported hand positions under different driving contexts, and actual observed hand positions. Hand positions were recorded as either 0, 1, or 2, which represented the number of hands in the target position (Thomas and Walton 2007)

Item	N	Mean	Median	Mode	SD
Actual observed hand positions	1196	1.02	1	1	0.74
Your hand positions when relaxed	542	1.27	1	1	0.69
The most natural hand positions when driving	543	1.51	2	2	0.65
Your typical hand positions when driving	544	1.71	2	2	0.50
Your typical hand positions when tense	542	1.92	2	2	0.32
The hand positions that give you most control over the vehicle	547	1.94	2	2	0.24

1.3 Theories of risk perception

A number of theories have been developed to explain the relationship between risk perception and driver behaviour. Individual differences in risk perception can be explained by theories such as sensation seeking. The influence of the driving environment on driver behaviour, perceived risk and actual risk can be partially explained by the theories of ‘risk homeostasis’, ‘perceptual countermeasures’ and ‘self-explaining roads’.

1.3.1 Individual risk and sensation seeking

Sensation seeking can explain differences in hand-position behaviour that are attributable to driver characteristics such as age and gender differences. For example, Zuckerman (1983) noted that sensation seeking peaks in adolescence and steadily declines with age thereafter, which Palamara and Stevenson (2003) noted is consistent with the developmental patterns of aberrant behaviour in young drivers.

Sensation seeking has often been used as an explanation for risk-taking behaviour. Zuckerman (1994 p27) defined sensation seeking as:

> *... a trait defined by the seeking of varied, novel, complex, and intense sensations and experiences and the willingness to take physical, social, legal and financial risks for the sake of such experiences.*

Zuckerman believed that monoamine transmitters such as dopamine, norepinephrine and serotonin underlie the trait of sensation seeking.

Jonah (1997) reviewed 40 studies examining the relationship between sensation seeking and risky driving, and found that 90% of the studies showed a significant positive relationship. Sensation seeking has also been associated with high-risk activities such as potentially dangerous experiments, risky sports vocations, criminal activities, sexual behaviour, smoking, heavy drinking and drug use (Zuckerman 1979a, 1994). High sensation seekers tend to have a lower appraisal of risk, and experience less anxiety in risky situations, than low sensation seekers (Horvath and Zuckerman 1993, Zuckerman 1979b).

1.3.2 Driving behaviour, perceived risk, and the driving environment

1.3.2.1 Risk homeostasis

Risk homeostasis theory describes how drivers adapt to their environment based on their perceived level of risk (Wilde 1982, 1988). This theory proposes that drivers continually monitor the risks in the environment to maintain a level of risk that they are willing to accept. Drivers adjust their behaviour (eg speed or headway) in an attempt to eliminate any discrepancy between the risk they perceive and the risk they are willing to accept. However, there is limited evidence for risk homeostasis in the real world (Lund and O'Neil 1986). For example, local rural roads and highways in the US present different actual levels of risk, yet highways have a lower fatality rate than rural roads (Evans 2004). If all drivers were modifying their driving behaviour to maintain a target level of risk, there would be no difference in road risk profiles across different roading contexts. However, driving behaviour and perceived risk have been shown to change as a consequence of the cues drivers receive from their environment (Colbourn 1978, Rundmo and Iverson 2004).

1.3.2.2 Perceptual countermeasures

Driving is primarily a visual task, and research into perceptual countermeasures indicates that altering elements of the visual road environment, such as reducing the apparent width of the road through narrow lane delineation, results in lower speeds (Godley et al 2004). Charlton (2003) demonstrated that by reducing an accident-prone intersection's approach sight distance from 100m to 25m, vehicle approach speeds were also reduced. Changing the sight distance could be viewed as increasing an intersection's *perceived* risk, as the drivers no longer had a clear view of the intersecting road, but reducing the *actual* risk – no serious or fatal accidents had occurred between installing the treatment and the time of publication of their research.

1.3.2.3 Self-explaining roads

The concept of self-explaining roads suggests that better road design, focusing on creating a predictable or consistent driving environment, will naturally encourage an expected driving style (van Vliet and Schermers 2000). Overseas research estimates that 50% of accidents are attributable to inaccurate perception of the information necessary to avoid the accident because of factors such as inadequate information, perceptual illusions, receiving information from multiple sources, environmental factors (eg night driving) and misleading road features (Hassan and Easa 2003, Heger and Schlag 2003).

1.4 Preliminary studies

As an initial component of this research, the reliability and face validity of the 'hands-on' measure was examined through two preliminary studies (see Fourie 2008 for more detail on these).

1.4.1 Preliminary study 1: reliability of the 'hands-on' method

The first preliminary study assessed inter-rater reliability, reliability across time and context, and the construct validity of the 'hands-on' method.

1.4.1.1 Methodology

One hundred observations of driver hand position were made at each of two sites: one in a 100km/h zone on State Highway 2, Lower Hutt, the other in a 50km/h zone on Cambridge Terrace, Lower Hutt. An Infrared Traffic Logger (TIRTL) measured the speed and headway of vehicles passing through the selected site.

1.4.1.2 Assessing consistency between raters

Two observers stood side-by-side on the side of the road. One observer randomly called out a selected oncoming car, and both observers wrote down the hand-position configuration they observed. Once 100 cars had been recorded at each site, their level of agreement was assessed. In addition to the standard measures of agreement, statistical analysis using 'Cohen's Kappa' (Cohen 1960) was used to control for agreement due to chance. The inter-rater reliability between the two observers was found to be 93% in a high-speed zone (100km/h) and 95% in a lower-speed zone (50km/h).

1.4.1.3 Assessing temporal reliability

Drivers' hand positions were observed in clear weather conditions at the same location on two separate days, at the same time of day (to ensure a similar traffic flow). There was no effect on hand position that could be attributed to time; a Chi-square analysis – $\chi^2(2,668) = 1.264$, $p > .05$, *n.s.* – indicated that hand positions were independent of the time of observation.

Table 1.3 Cross tabulation of the number of drivers observed placing zero, one and two hands on the top half of the steering wheel, over consecutive days

Number of hands on top half of steering wheel		Day 1	Day 2	Total
Zero	Observed	74	75	149
	Expected	72	77	
	Adjusted residual	0.32	-0.32	
One	Observed	152	151	303
	Expected	147	156	
	Adjusted residual	0.78	-0.78	
Two	Observed	98	118	216
	Expected	105	111	
	Adjusted residual	-1.12	1.12	
Total		**324**	**344**	**668**

1.4.1.4 Assessing contextual reliability

The two observers simultaneously and independently measured drivers' hand positions in two situations that were deemed to be similar; ie north- and southbound traffic on the same stretch of State Highway 2. There was no effect of context (ie driving northwards or southwards on the same stretch of state highway) on the proportion of drivers showing each hand position; a Chi-square analysis ($\chi^2(2,668) = 0.441$, $p > .05$, *n.s.*) indicated that hand position was independent of direction of travel.

Table 1.4 Cross tabulation of the number of drivers observed placing zero, one and two hands on the top half of the steering wheel, for north- and southbound traffic

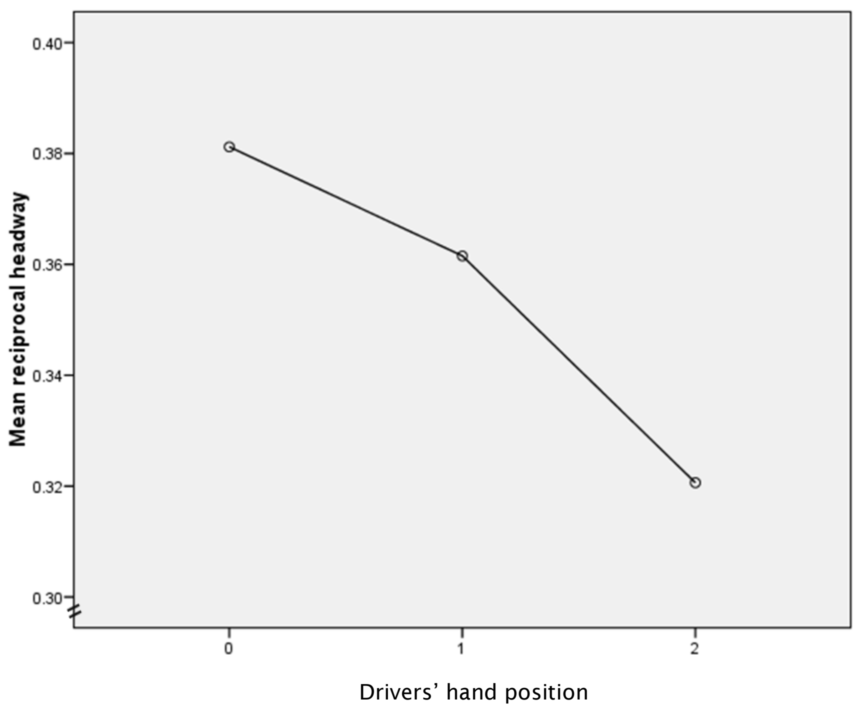
Number of hands on top half of steering wheel		Northbound	Southbound	Total
Zero	Observed	73	76	149
	Expected	74	75	
	Adjusted residual	-0.15	0.15	
One	Observed	147	156	303
	Expected	150	153	
	Adjusted residual	-0.49	0.49	
Two	Observed	111	105	216
	Expected	107	109	
	Adjusted residual	0.66	-0.66	
Total		**331**	**337**	**668**

1.4.1.5 Assessing construct reliability

The construct reliability of the hand-position measure was examined against speed selection and headway acceptance, which are constructs that are known to relate to accident likelihood. Speed measures were taken for the 'free speed' of the vehicle at the head of the platoon (ignoring the rest), with the 'head of the platoon' defined as a vehicle with a headway of greater than 6 seconds. Headway is defined as the gap acceptance of vehicles when constrained by a vehicle in front with less than 4 seconds headway. Other vehicle with larger 'gaps' are ignored for headway calculations because they can then be considered as travelling with 'free speed'; ie not restrained by a vehicle in front of them.

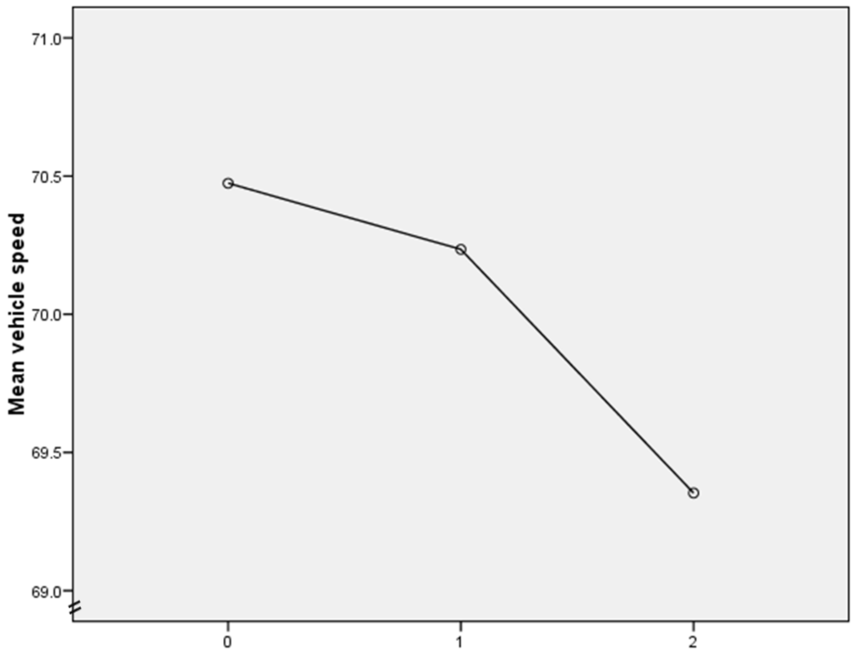
As can be seen in figure 1.2 on the next page, drivers who placed no hands on the top half of the steering wheel had the largest reciprocal headways (indicting greater risk taking), followed by drivers who placed one hand or two hands, respectively, on the top half of the steering wheel.[2] A similar pattern was seen for average speeds, with drivers who placed no hands on the top half of the steering wheel driving faster than drivers who placed one hand or two hands, respectively, on the top half of the steering wheel (see figure 1.3). This speed finding differs from that found by Thomas and Walton (2007), as in our study, individual speeds within a speed zone were being examined, rather than differences between speed zones.

Figure 1.2 Mean reciprocal headway (in seconds) of drivers with zero, one and two hands on the top half of the steering wheel



2 Evans and Wasielewski (1983) note that when examining headway, the most effective approach for discriminating between different driver groups (or different hand positions, in this case), is to use the reciprocal of headway. The reciprocal refers to the multiplicative inverse (ie 1/headway).

Figure 1.3 Mean vehicle speed (in kilometres per hour) of drivers with zero, one or two hands on the top half of the steering wheel



Drivers' hand position

1.4.1.6 Summary of reliability study

The hand-position measures demonstrated reliability across all of the measures examined, including: acceptable levels of inter-rater reliability (across both 100kph and 50kph speed zone conditions), temporal reliability (across different days), contextual reliability (across different directions of traffic in the same location) and construct reliability (correlating with speed and headway acceptance).

1.4.2 Preliminary study 2: drivers' attitudes to risk and hand position

The second preliminary study examined the face validity of hand positions as a measure of perceived risk. A survey of drivers was used to examine the relationship between:

- observed hand positions
- reported hand positions
- perceptions of hand positions, risk taking, optimism and confidence when driving.

This study continued on from previous work by Thomas and Walton (2007) that established that hand positions were perceived to have a positive relationship with driver tension.

1.4.2.1 Methodology

This study entailed a small-scale survey of drivers conducted in conjunction with observations of hand position. A sample of 630 drivers (excluding drivers of heavy vehicles, motorbikes and easily identifiable commercial vehicles such as taxis) was observed on Eastern Hutt Rd, Lower Hutt (an 80km/h road). Surveys were sent to 500 of these drivers (250 males and 250 females). Two hundred and thirty-three were returned (a 46.6% response rate) – 116 males, 116 females, 1 unknown – with a mean age of 49.83 years (SD = 15.13).

Repeated observations were made on different days in an attempt to minimise external variables that could influence perceived risk (eg pedestrians, cyclists, domestic pets, intersections, turning vehicles, etc). Observations were made in clear weather conditions. A TIRTL measured the speed and headway of vehicles passing through the selected site. Hand positions were recorded according to the method of Walton and Thomas (2005), where the number of hands in the target zone on the top half of the steering wheel (between 3 o'clock and 9 o'clock on an analogue clock face) was recorded as zero, one or two. A video camera was synchronised with the TIRTL. Observers sat in a light commercial van to provide greater safety and better elevation for viewing hand positions. Hand positions, driver gender and vehicle number plate were spoken into the video camera as the cars passed the vehicle – the first observer called out the driver gender and driver hand position, after which observer two called out the associated vehicle number plate.

Address details linked to each licence plate were obtained from the Motor Vehicle Registry in Palmerston North, New Zealand. A questionnaire was constructed to measure a number of driver characteristics, attitudes and behaviours. These included driver age, gender, exposure to vehicle travel, vehicle transmission, optimism bias, risk taking, confidence, hand-position beliefs and self-reported hand position. For the purposes of this study, only the variables optimism bias, risk taking, confidence, hand-position beliefs and self-reported hand position were measured by the questionnaire. To ensure anonymity, no personal information was requested in the questionnaire.

As mentioned earlier, the questionnaires were sent to 500 drivers (250 females and 250 males) whose actual behaviour had been observed. Data was stratified, based on gender and hand position whereby questionnaires were sent to 250 females (90 of whom were observed with two hands on the top half of the steering wheel, 111 with one hand on the top half of the steering wheel, and 49 with zero hands on the top half of the steering wheel) and 250 males (48 of whom were observed with two hands on the top half of the steering wheel, 134 with one hand on the top half of the steering wheel, and 68 with zero hands on the top half of the steering wheel). This was done to mitigate any gender biases and achieve a good distribution of self-reported hand positions.

1.4.2.2 Questionnaire

The questionnaire measured four variables that were hypothesised to influence driver hand position – optimism bias, risk-taking behaviour, driver confidence, and driver belief around hand position and control of the vehicle. A copy of the questionnaire can be found in appendix A.

Optimism bias was measured using nine items developed by Dejoy (1992). Risk-taking behaviour was measured using three scales (15 items) designed by Ulleberg and Rundmo (2003) to measure self-reported acts of risk taking in traffic – speeding, rule violations and self-assertiveness. Driver confidence was measured using a seven-item driver-confidence scale created by Parker et al (2001). Driver's belief that placing two hands on the top half of the steering wheel will give increased control was measured using a six-item scale.

Self-reported driver hand position was measured using five items that asked individuals what hand position they would adopt under different circumstances. Items included 'your typical hand position when driving' and 'your hand position when tense'. The questionnaire included a figure depicting three potential hand-position placements – two hands on the top half of the steering wheel, one hand on the top half of the steering wheel, and zero hands on the top half of the steering wheel (as shown earlier in figure 1.1, but without the accompanying text). Respondents were required to tick the hand position that best described the hand position they tended to adopt. Jonah (1990) noted that direct observations of driver behaviour are needed to validate self reports. To establish the convergent validity of the scale, drivers' self-reported positions should correlate with the single observation of driver hand position.

Gender differences were examined to ensure that the gender bias in driver hand position had been adequately controlled for in the stratification process. Of the surveys returned, a t-test revealed no significant gender differences in observed driver hand position (t (230) = -0.183, $p > .05$, *n.s.*), or self-reported driver hand position (t (229) = -1.223, $p > .05$, *n.s.*).

1.4.2.3 Attitudes to risk and hand position on the steering wheel

Observed drivers' hand positions correlated significantly with their self-reported hand positions ($r = .219$, $p < .01$).[3] This finding demonstrates that self-reported hand position has convergent validity. Observed hand position did not correlate significantly with other variables measured (see table 1.5). A limitation may lie in that even though data was excluded if the observed gender did not match the survey gender, it would be presumptuous to assume that all the surveys were completed by the actual driver who was observed. In addition, single observations suffer from significant measurement error and have been criticised as not being useful in testing hypotheses unless they can be compared to observations made by other researchers (King et al 1994). The psychological variables measured examined general driver behaviour, whereas observed hand position was context-specific. Hence, self-reported hand position was used to further examine the relationships between hand position and the psychological variables measured.

Table 1.5 Correlations of psychological variables, self-reported hand position and observed hand position, where observed gender matched the survey gender (N=183) (Fourie 2008)

	Items	M	SD	1	2	3	4	5	6
1 Optimism bias	6	4.06	3.18	(.70)					
2 Risk taking	14	20.11	4.57	-.12	(.83)				
3 Driver confidence	12	50.41	5.59	.21[b]	-.10	(.86)			
4 Hand-position beliefs	6	24.04	3.64	.03	-.11	-.04	(.70)		
5 Self-reported hand position	5	8.53	1.84	-.16[a]	-.25[b]	-.03	.26[b]	(.80)	
6 Observed hand position	1	1.07	0.71	-.08	-.05	-.11	.02	.22[b]	(N/A)

(a) significant at $p < .05$

(b) significant at $p < .01$

Individuals who reported higher risk-taking behaviour tended to report placing fewer hands on the top half of the steering wheel. Optimism bias was positively related to confidence, whereby individuals who reported being highly optimistic with regard to their safety, skill and likelihood of accident also tended to report being more confident drivers. Optimism bias was also found to be negatively related to self-reporting of hand position, whereby highly optimistic drivers reported placing fewer hands on the top half of the steering wheel. Optimism bias did not significantly relate to risk taking. Individuals with stronger beliefs regarding the importance of hand positions in controlling the vehicle reported placing more hands on the top half of the steering wheel.

Drivers who tended to place more hands on the top half of the steering wheel reported less risk taking, less optimism bias, and had stronger beliefs that hand position is related to control of the vehicle.

3 Cronbach's Alpha was used to assess the internal reliability of the scales. All items had a reliability coefficient of above 0.7, which Nunnaly (1978) indicated to be an acceptable reliability coefficient.

1.4.2.4 Summary of attitudinal study

This study found that observed hand positions were not related to any of the psychological variables measured apart from self-reported hand positions. Self-reported hand positions were related to, and could predict, a driver's reported level of risk taking – ie the general impression they have of their own behaviour while driving. This finding supported the hypothesis that driver hand position is related to risk taking. Ideally, the measures of risk taking would have predicted the actual behaviour of the drivers, as measured by their observed hand positions when they were selected for this study as described earlier. In this case, however, the actual behaviour of an individual was represented by a single point in time recording observed hand positions in a single driving context. Self-reported hand positions included a range of hand positions that a driver would adopt across a number of driving contexts.

Self-reported hand positions could also be predicted by drivers' beliefs about hand position – drivers with a strong belief that placing both hands on the top half of the steering wheel gave them more control were more likely to report doing exactly that. Similarly, self-reported hand positions could be predicted by the level of optimism bias of the driver – drivers who believed themselves to be safer, more skilful, and less likely to have an accident than the average driver tended to report placing more hands on the top half of the steering wheel. The hypothesis that driver confidence would relate to driver hand position was not supported either for observed hand position or self-reported hand position. However, overall it was found that hand position was related to reported risk-taking behaviour.

1.5 Conclusions of the preliminary studies

The key findings of these preliminary studies about the 'hands-on' method of assessment were as follows:

- The method has an acceptable level of inter-rater consistency, indicating that observers can easily be trained to record hand positions accurately on a simple ordinal scale.
- The measure has face validity, in that it is a proxy measure of perceived risk and does correlate with other subjective measures of risk, along with self-reports on the relationship of hand position to levels of perceived risk.
- The method is robust within similar contexts, and is consistent over time – ie it is a reliable measure.
- The technique achieves concurrent reliability, strongly correlating with individual speed and headway choices.
- The method replicates other findings relating driver characteristics to perception of risk, including a lower risk perception in males and SUV drivers, as revealed by a greater likelihood to drive with zero hands on the top half of the steering wheel.

2 Methodology

The two preliminary studies provided satisfactory evidence that the driver hand-position method was reliable, robust and appropriate for use in the primary study to evaluate the effectiveness of improved delineation, albeit that the preliminary studies evaluated the method in a relatively straightforward context in the daytime, in good conditions. Nonetheless, it was considered that the hand-position methodology provided a more sensitive measure of driver responses to changes in the road context than other outcome measures, such as speed or headway – ie the 'hands-on' method could be used to evaluate drivers' responses to delineation treatments that had so far been difficult to assess using the usual techniques available to researchers. This section of the report outlines the way roadmarking delineation, across different sites and visibility conditions, was evaluated using measures of driver speed selection, headway acceptance and hand position.

Three sites were selected to examine the influence of roadmarkings on driver behaviour under various driving conditions (the rationale for site selection is outlined in section 2.2.1). The key premise was that dry daytime conditions offered 'ideal' visibility, and drivers managed these conditions with a consistent pattern of behaviour, observable using the measures we have described (speed, headway and hand positions). Therefore any detectable difference in driver behaviour would indicate a change in drivers' perceived risk, which was expected to correlate to changes in actual risk. (However, the base case here is not 'high or low risk' *per se*, but 'visibility', as we are concerned with the effect of linemarkings on driver behaviour.) Dry daytime conditions have the best visual conditions for driving, and the assumption is that drivers manage these conditions with a consistent pattern of behaviour, observable using the measures we have described. It was expected that degraded visual environments would produce different patterns of driver behaviour, such as placing more hands on the top half of the steering wheel. Thus, any change towards the 'daytime' reference would be indicative of improved road delineation.

The notion of 'risk' enters the background theory surrounding the use of the new measures, and is subject to some controversy, but it is not absolutely necessary to consider the hand-position measure as an indirect measure of perceived risk for the method and the analysis considered here.

2.1 Conditions

The purpose of this research was to test an evidence-based method for quantifying the performance of roadmarkings. It was hypothesised that as the brightness of the roadmarking improved, drivers would perceive the night-time visual environment as being similar to daytime (ideal) visual conditions, and therefore tend towards their daytime level of perceived risk. This shift would be shown by a return to daytime levels of speed, headway acceptance and hand position on the steering wheel. Therefore, the performance of the delineation treatment could be measured by a relative shift to daytime driving behaviour within each site.

Data was collected at each of the three selected sites, in dry weather under both daytime and night-time conditions. Data was also collected under wet daytime conditions at Kaitoke, and both before and after the delineation improvement (also daytime and night-time conditions) at Alexander Rd (see figures 2.2 and 2.3 for the full range of conditions at these sites).

2.1.1 Wet conditions

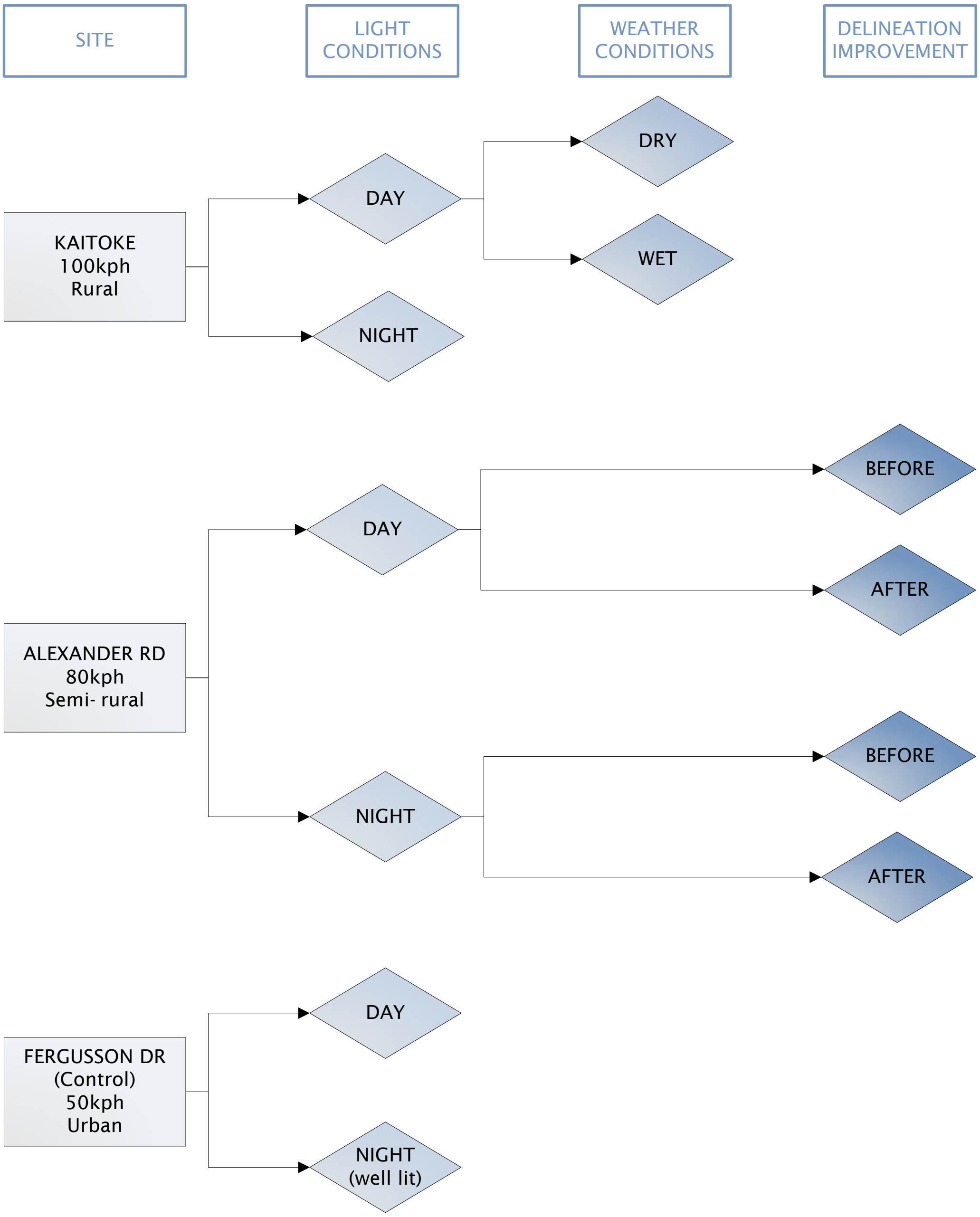
The level of rainfall for the wet condition at the Kaitoke site was measured by an AC013 Rain Collector (shown later in figure 2.7) – the heavy-rainfall level was 10.2mm/hr.

2.1.2 Delineation intervention

Since a key component of the project involved the evaluation of the effect of upgraded roadmarkings, data on driver hand position, vehicle speed and vehicle headway was collected before and after the new roadmarkings were laid on a section of road.

A Zehntner Retroreflectometer was used to assess the levels of retroreflectivity (Rl) in night-time conditions at the Alexander Rd site before and after the roadmarking intervention. Before the upgrade, the roadmarkings had an average of 38.08Rl (*SD* = 26.20), and after the upgrade, an average of 141.92Rl (*SD* = 15.68). The retroreflectivity level before the intervention was well below the recommended New Zealand standard of 100Rl. The high variation in retroreflectivity for the roadmarkings prior to the upgrade was probably because there was uneven wear over time, due to variable vehicle exposure on different sections of the road.

Figure 2.1 Experimental test conditions



2.2 Sites

The original intention of the research was to select a single site. However, because the initial results of the research provided counter-intuitive findings that required significant re-working to ensure that what we observed was accurate, the following three sites were used for the project:

1 Kaitoke – a 100kph speed zone rural road near the northern end of the Kaitoke Loop Rd on State Highway 2

2 Alexander Rd – an 80kph speed zone semi-rural road in Upper Hutt

3 Fergusson Drive (control site) – a 50kph speed zone urban road near Totara Street, in Upper Hutt.

The three sites were used for case-control comparisons using different features of each location, as described in each section below. The basic procedure was consistent across each site, using the same observers in elevated positions. Where the features of the road did not allow a good viewing angle, the observers positioned themselves on the roof of the van to achieve a consistent perspective on the drivers' hand positions.

2.2.1 Rationale for introducing additional sites

2.2.1.1 Alexander Rd

The Alexander Rd site was introduced because there was no detectable difference between daytime and night-time driving behaviours at Kaitoke. Apart from a failure of the method, there were two factors that could have accounted for this.

First, it was supposed that if the roadmarkings at the Kaitoke site were of high quality and high visibility, they could be making the night-time driving conditions similar to daytime conditions – that is, the markings were creating conditions equivalent to a daytime driving environment. If true, this conclusion would have had significant implications for the linemarking industry, because the physical attributes of these linemarkings were not particularly good and yet they were performing well.

Second, it was supposed that the type of driver in night-time conditions might be different, masking the effect of night-time driving through behaviour we were not monitoring. For example, it was posited that the northbound traffic at night might mainly consist of locals who were familiar with the road (and therefore drove with relaxed hand positions), or a limited number of drivers who were travelling intercity, or some other feature. The basic logic of the method requires the general characteristics of sampled drivers to be consistent across observations at different times. While we had no real reason to believe this assumption had been violated, we wanted to check for the possibility.

The Alexander Rd site was selected because it was an urban driving environment that had poor roadmarkings with significantly lower retroreflectivity (38Rl) than the Kaitoke site (220Rl).

2.2.1.2 Fergusson Drive (control site)

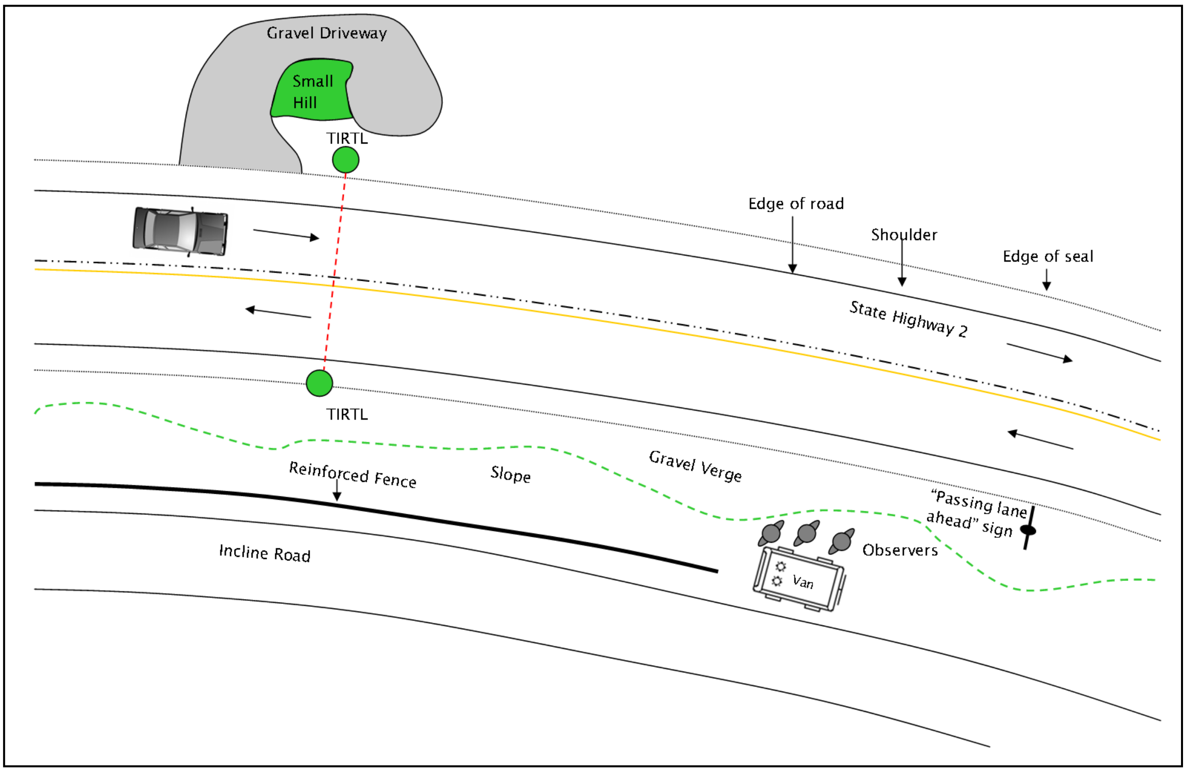
The Fergusson Drive site was required as there was no observable difference in driver behaviour between daytime and night-time conditions at either the Kaitoke or the Alexander Rd site. It was posited that there could be different characteristics in the sample of night-time and daytime drivers that were confounding the relationship between roadmarking visibility and driver behaviour.

This site was chosen because the high level of street lighting meant that the visibility change between daytime and night-time was essentially controlled (there was no street lighting at the other sites). Controlling for the lighting conditions meant that any change in hand positions was likely to be a function of a different composition of drivers during night-time conditions.

2.2.2 Kaitoke (State Highway 2)

The Kaitoke site (shown in figure 2.2) was a 100kph rural site on State Highway 2. The observers were in an elevated position (on a roadside bank) approximately 4m above the road, which provided a good view of the entire steering wheel of passing vehicles. So that the observers did not need to look through the vehicle to see the driver's hands, only the vehicles in the far lane to the observers were observed (an advantage especially at night). These vehicles were heading north (away from the main urban centre of Wellington) and on to a stretch of intercity highway. The curve ahead of the site was a modest bend that was signposted with curve advisory speed.

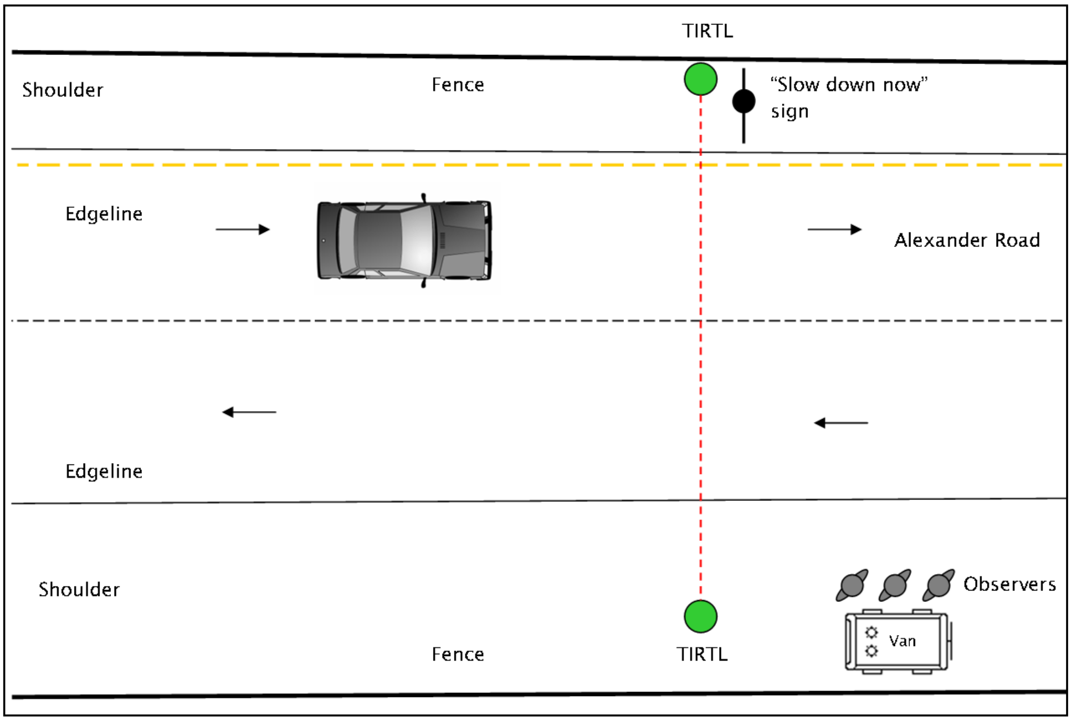
Figure 2.2 The Kaitoke site layout, including the location of the TIRTL units (measuring speed and headway) and the observation location



2.2.3 Alexander Rd

The Alexander Rd site was in an 80kph speed zone site in Upper Hutt (see figure 2.3). The linemarkings at this site had relatively low retroreflectivity (30Rl). The traffic in the far lane to the observers was travelling north and approaching a moderate horizontal curve in the road 300m ahead.

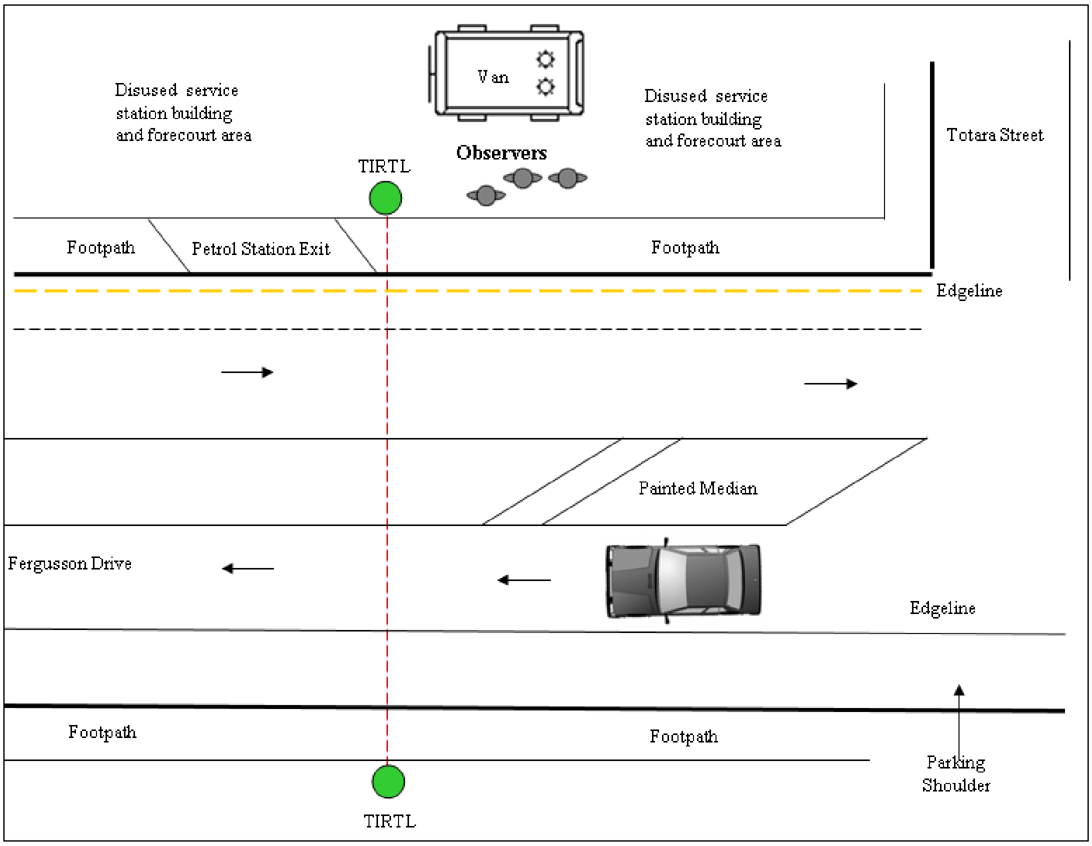
Figure 2.3 The Alexander Rd site layout, including the location of the TIRTL units (measuring speed and headway) and the observation location



2.2.4 Fergusson Drive (control site)

The Fergusson Drive site was in an urban 50kph speed zone in Upper Hutt (see figure 2.4). Unlike the other sites, this site had street lighting, so the visibility of the road, or sight distance of drivers, was not expected to differ between daytime and night-time conditions. Vehicles travelling in the far lane from the observers were heading east along a straight road for at least 500m in each direction. In this location, observers were usually seated on top of the van roof to get a better viewing angle.

Figure 2.4 The Fergusson Drive site layout, including the location of the TIRTL units (measuring speed and headway) and the observation location



2.3 Adaptation of the 'hands-on' method for night-time conditions

A key task of this project was to modify the 'hands-on' method for use at night, when hand positions were more difficult to observe. Various techniques and technologies were examined (see appendix B for more detail). The key prerequisites were:

1 providing enough light to detect drivers' hand positions

2 ensuring the light sources and equipment setup did not create a hazard to motorists

3 ensuring that motorists maintained their natural driving behaviour.

Low-light conditions (ie full moon on a clear night) and infrared lighting were tested, with the preferred method being infrared lighting because an infrared camera can capture information outside the visible spectrum[4], making unobtrusive imaging possible even in night-time conditions where little or no visible

4 The human eye is sensitive to wavelengths of light in the range 450–750 nanometres (nm). Wavelengths longer than 750nm are known as infrared, and are invisible to the human eye. Infrared cameras operate with wavelengths as long as 14,000nm (14µm). By capturing information from outside the visible spectrum, and then reproducing it as visible light, an infrared camera is able to use light that is otherwise 'wasted' by the human eye.

light is available. The night-vision equipment that was selected and successfully trialled is described in the next section.

2.4 Equipment

2.4.1 Night vision

The two observers used ATN NVG7-2 Generation 2 night-vision goggles to identify night-time hand positions. These use Microchannel Plate (MCP) technology that enhances image quality and amplification. A perpendicular observation angle to the vehicles was taken in order to reduce the glare from vehicle headlights. The night-vision goggles also had automatic bright-light shut-off to further reduce the influence of headlight glare.

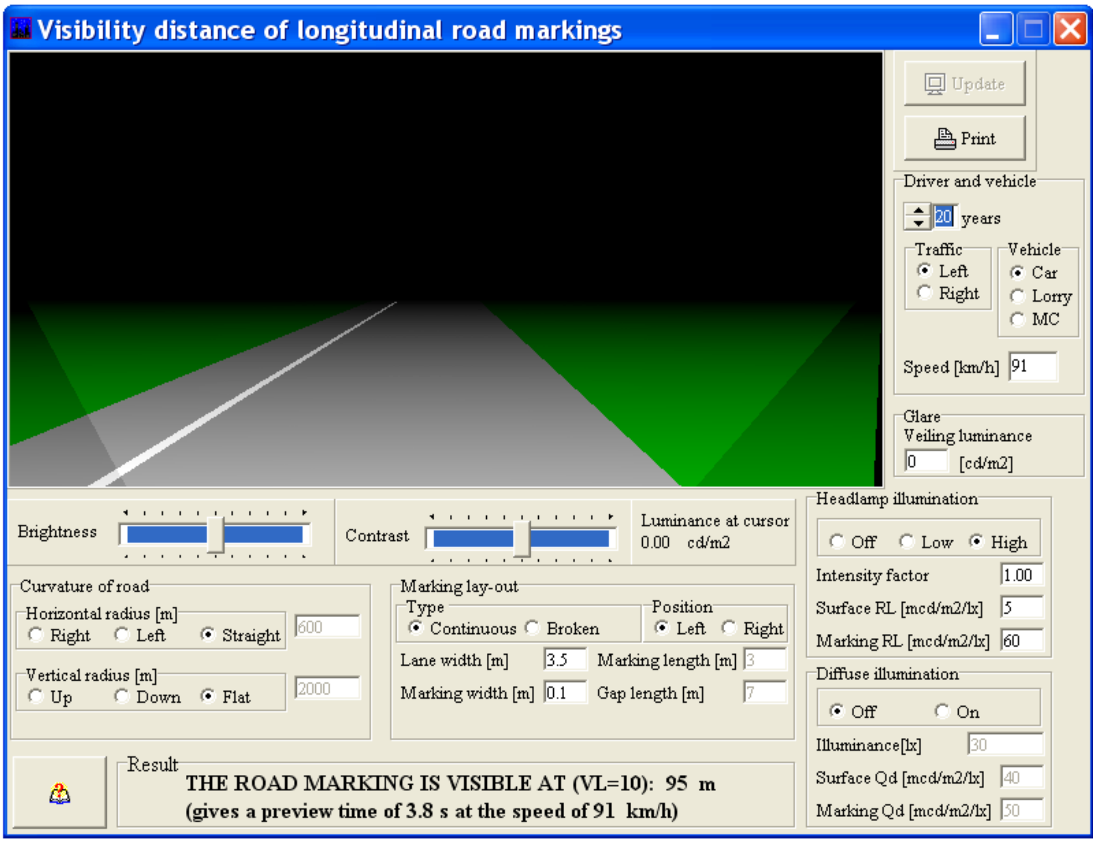
Each target vehicle was illuminated by a person using two hand-held infrared spotlights. These spotlights amplified incoming visible or near-infrared light, so that the resulting image was of a higher intensity (contrast). A picture of the spotlight (without the infrared lens) is shown in figure 2.5.

Figure 2.5 The Generation 2 night-vision goggles (left) and handheld spotlight (right)

2.4.2 Retroreflectivity

A Zehntner Retroreflectometer was used to assess levels of retroreflectivity (Rl) for night-time conditions before and after the roadmarking intervention at the Alexander Rd site. The visibility distances under the different markings were calculated using visibility software (see figure 2.6). This software program was developed as part of the 1999 European Co-operation in the Field of Scientific and Technical Research (COST) project. Information regarding roadmarking retroreflectivity, roadmarking width, headlight information (dipped or full beam), lane width, vehicle type and driver age were input into the software program.

Figure 2.6 An example output from the visibility software program that provided the roadmarking visibility distance in metres and seconds



2.4.3 Rainfall measurement

Rainfall was measured using an AC013 Rain Collector (see figure 2.7), which consists of a collection cone and two tipping buckets and has an accuracy of +/- 0.2mm. (The AC013 meets the requirements of the World Meteorological Association.)

Rain enters the cone of the collector, passes through a debris-filtering screen and tips when 0.2mm of rain has collected. The rainfall data was monitored and collected using a MultiLogPro portable data logger.

Figure 2.7 An AC013 Rain Collector showing the collection cone and a view of the interior tipping mechanism

2.4.4 Speed and headway measurement

The Infrared Traffic Logger (TIRTL) is a sophisticated traffic-logging system that gathers time-and-date-stamped information on vehicle speed and vehicle type. The TIRTL uses infrared beams to measure traffic flows, meaning there are no cables placed on the road that might be moved or damaged.

The beams were set up to be at wheel height (see figure 2.8), so that vehicle type (eg motorbike, truck, towing vehicle) could be calculated from the wheel size and spacing, and the direction of the traffic was recorded. This allowed trucks, motorbikes and vehicles travelling in the wrong direction, for which we were not collecting hand-position data, to be removed from the sample.

Figure 2.8 The Infrared Traffic Logger (TIRTL) roadside setup, with devices placed on opposite sides of the road to record traffic speed, headway and vehicle types

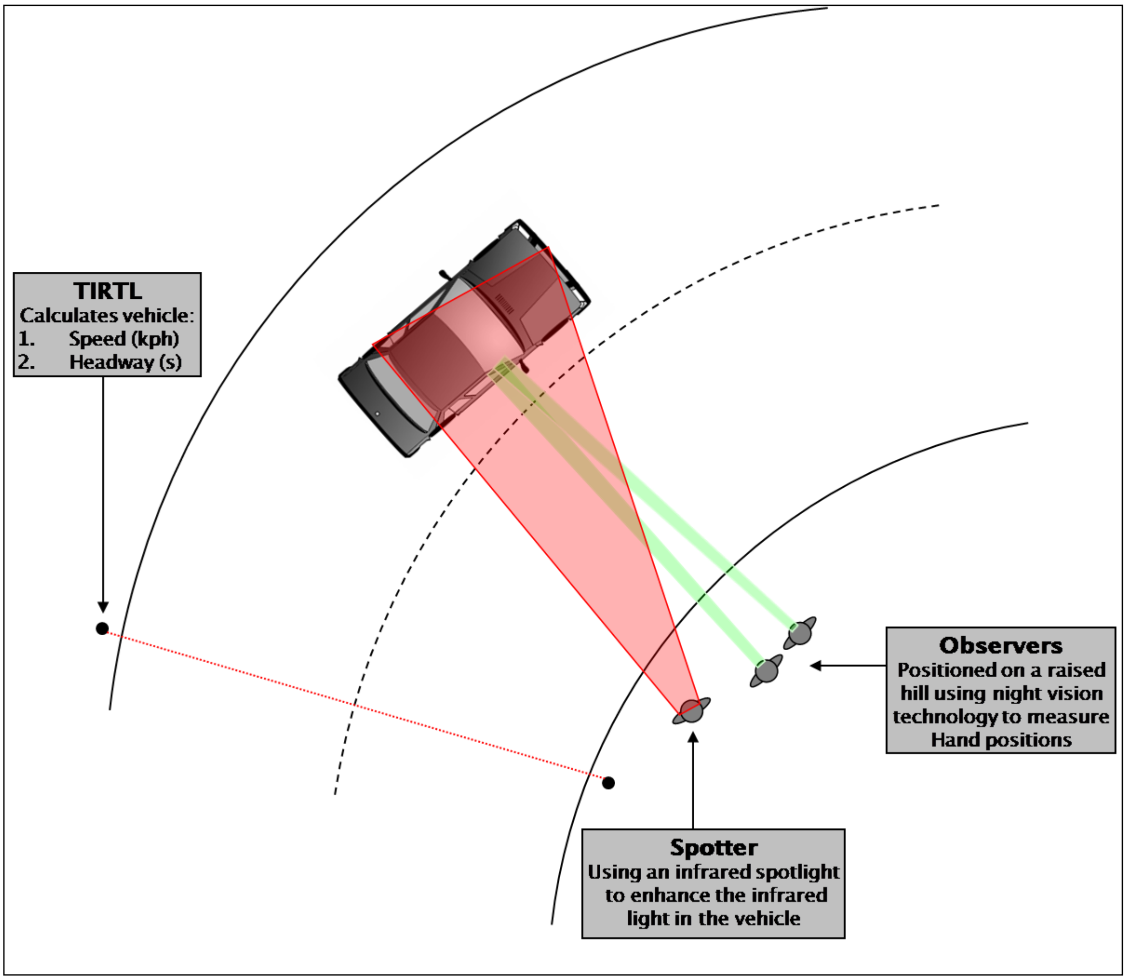
2.4.5 Procedure

The TIRTL equipment was set up on opposite sides of the road. A laptop was connected to the TIRTL and TIRTLSoft software was used to ensure the equipment was accurately recording traffic flows.

As described earlier, hand-position observations were made from an elevated position (either on a roadside bank or on top of a motor vehicle). Only vehicles in the far lane from the observers were examined, as this made it easier for observers to see the drivers' hands. Hand positions were recorded independently by two trained observers. Hand-position data was only included in the analyses where both observers recorded the same hand position (see section 2.5.2 for more detail regarding data collection of hand positions). A third person used the hand-held infrared spotlights to enhance the level of infrared light in each target vehicle.

Observers recorded the start and finish times of hand-position collection, to ensure all TIRTL data matched the same time period. Figure 2.9 shows an example layout of the equipment used to gather vehicle speeds and headways, and driver-hand positions, in night-time conditions. The same setup was used for daytime conditions, but without the use of night-vision equipment or the person using the infrared spotlights. Dictaphones were used to record the observations at night, while pen and paper were used during the day. Perceived driver age was collected at the Fergusson Drive site, where the lighting conditions were good enough to make out driver characteristics.

Figure 2.9 An example of the equipment setup for night-time observations and measurements (not to scale)



2.5 Dependent measures

2.5.1 Speed and headway

Speed and headway were recorded using the TIRTL. Headway acceptance was measured for any vehicles that were following within four seconds of another vehicle. (Wasielewski (1979) found that the characteristics of vehicles with a headway larger than four seconds were not statistically different from vehicles travelling in very sparse traffic.)

2.5.2 Hand positions

The hand position of each driver was recorded by two independent observers, following the method laid out by Walton and Thomas (2005)[5]. If the observers did not agree on the hand position, or simply did not record the data (ie they missed the driver), the data was not included in the analyses.

5 The method used an ordinal categorisation of hand positions, where the 'target zone' for hand placement on the steering wheel was between the 9 o'clock and 3 o'clock positions on an analogue clock face.

Table 2.1 Ordinal hand-position category and description

Hand-position category	Description
Zero hands	No hands visible on the top half of the steering wheel (between 9 o'clock and 3 o'clock on a clock face)
One hand	One hand visible on the top half of the steering wheel (between 9 o'clock and 3 o'clock on a clock face)
Two hands	Two hands visible on the top half of the steering wheel (between 9 o'clock and 3 o'clock on a clock face)

2.5.3 Perceived driver age

Perceived driver age was collected to examine whether:

1 the age characteristics of drivers varied between daytime and night-time conditions

2 hand position was related to age group.

A broad measure of perceived driver age was collected at the Fergusson Drive site, where the good light conditions made it possible to examine driver characteristics in both daytime and night-time conditions. The measure broadly categorised drivers who looked 60 or more years of age into an 'older' age group, and drivers who looked younger than 60 years of age into an 'other' age group.

3 Data analysis

3.1 Driver observations

Two field observers examined the hand positions of a total sample of 3211 vehicle drivers. About 4.7% (n = 152) of these observations were missed by one of the observers and were therefore not included, and an additional 5.1% (n = 163) were removed because of inconsistency in the inter-rater categorisation of hand positions, leaving a final sample of 2896 vehicle drivers.

The hand-position agreement levels and tests of inter-rater reliability (using Cohen's Kappa) are presented in table 3.1, and reveal that the observational measures were at acceptable levels of agreement for all conditions except for wet daytime conditions. Wet conditions reduced reliability down to 85% agreement (Kappa value of 0.73), because of reduced visibility. Kappa values above 0.80 are acceptable in most situations (Lombard et al 2008). There was little difference in inter-rater agreement between daytime and night-time findings, indicating that the method and equipment worked well at night.

Table 3.1 Inter-observer agreement and hand positions, by site condition

						% hand position category		
Site	**Condition**	**N**	**% observer agreement**	**Kappa**	**P**	**Zero hands**	**One hand**	**Two hands**
Kaitoke	Day	519	92.7%	0.88	***	20.2	44.7	35.1
	Night	252	94.4%	0.91	***	24.6	44.8	30.6
	Day wet	180	84.5%	0.73	***	10.6	36.1	53.3
Alexander Rd	Day	483	96.6%	0.95	***	25.3	45.8	29.0
	Night	146	98.6%	0.98	***	27.4	41.8	30.8
	Day – repeat	485	97.0%	0.95	***	23.1	45.2	31.8
	Night – repeat	113	95.8%	0.93	***	36.3	44.2	19.5
Fergusson Dr	Day	483	96.6%	0.95	***	28.8	47.8	23.8
	Night	235	92.9%	0.89	***	33.2	43.0	23.8
Overall		2896	95.0%	-		24.8	44.6	30.6

*** $p < .001$

3.2 Effects of wet conditions on driver behaviour

The wet condition at Kaitoki had a rainfall level of 10.2mm/hr, which is heavy rain, and the driving conditions were difficult. The degradation of linemarking conspicuity under wet conditions can be seen in figure 3.1.

Figure 3.1 Linemarkings in dry (left) and wet (right) conditions

Table 3.2 (on the next page) records the frequency of observed hand positions at the same site in two different conditions. In the heavy-rainfall condition, 53% of drivers had two hands on the top half of the steering wheel, which is higher than any of the other observations (X^2 (4, *N* = 951) = 29.54, $p < .001$), and the highest rate we have observed at any site (see Walton and Thomas 2005). During the night-time condition (described in section 3.3) fewer drivers adopted the 'two-hand' position, indicating that rain affected the drivers' visual environment more strongly than darkness. (We recognise that the result for the night-time condition may have partly been an artefact of the driver demographics at this site. This possibility was the reason we included additional sites where we considered whether the samples changed across the different times of observation). In wet conditions, drivers were more than twice as likely (odds ratio = 2.16, *CI* = 1.50-2.99, $p < .001$) to place both their hands on the top half of the steering wheel, indicating a higher level of perceived risk, than in dry daytime conditions (X^2 (1, *N* = 699) = 18.62, $p < .001$). Likewise, drivers were 2.6 times as likely (odds ratio = 2.60, *CI* = 1.75-3.86, $p < .001$) to adopt a '10 o'clock/2 o'clock' hand position in wet daylight conditions than in dry night-time conditions. Note that the dry daytime conditions (considered here to be a baseline comparison) were the same as those in section 3.3, which considers the difference between daytime and night-time driving behaviours.

Table 3.2 Cross tabulation of hand positions across daytime, night-time and wet daytime conditions at Kaitoke – significant effects (those with adjusted residuals over 1.96) are highlighted in bold

		Number of hands on top half of steering wheel			Total count
		Zero hands	One hand	Two hands	
Day	Observed count	105	232	182	519
	Expected count	101.51	223.75	193.74	519
	% hand position	20.23	44.70	35.07	100
	Adjusted residual	0.57	1.08	-1.58	
Night	Observed count	62	113	77	252
	Expected count	49.29	108.64	94.07	252
	% hand position	24.60	44.84	30.56	100
	Adjusted residual	**2.35**	0.65	**-2.59**	
Wet day	Observed count	19	65	96	180
	Expected count	35.21	77.60	67.19	180
	% hand position	10.56	36.11	53.33	100
	Adjusted residual	**-3.38**	**-2.11**	**4.93**	
Total count		186	410	355	951

3.2.1 Speed and headway in wet conditions

In wet conditions, average vehicle speeds were significantly lower (by about 9kph) than normal speeds in dry conditions, and there was also a substantial drop in speed variation (see table 3.3).

Table 3.3 Descriptive statistics and the significant difference for speed between dry and wet conditions

	Dry			Wet			Difference	
Variable	N	M	SD	N	M	SD	t	p
Speed	314	93.28	9.10	19	84.11	5.32	-4.35	.001

Note: During wet conditions, the TIRTL only collected data sporadically, probably because of water displacement as the vehicle passed. Therefore only 19 records were collected for speed, and none for headway.

3.2.2 Accident records in wet conditions in New Zealand

The proportions of injury and fatal crashes in New Zealand for wet versus dry conditions are contained in *Motor vehicle crashes in New Zealand 2008* (MoT 2009). Table 3.4 outlines the frequency of injury and fatal crashes under different weather and light conditions. The table shows that about 16% of injury accidents, and 17% of fatal accidents, occur when it is raining.

According to 1971–2000 meteorological data collected by NIWA, an average of 120 days per year in New Zealand have at least 1mm of rain (NIWA 2010), and about 40 days have at least 2mm of rain (the latter meeting the formal definition of a wet or rain day, according to Metcheck (2010)). Under this definition of a wet day, New Zealand drivers would be exposed to wet driving conditions for up to 11% of the year (ie 40 wet days out of 365). The likelihood of having rain for every hour of the wet day is low, so this measure is relatively high.

Therefore, accident exposure under wet conditions is slightly over-represented in the chart, although under this crude measure of exposure, this difference is not significant for either injury accidents (X^2 (1, N = 10607) = 2.11, $p > .05$, n.s.) or fatal accidents (X^2 (1, N = 655) = 2.77, $p > .05$, n.s.).

Table 3.4 Frequency of injury accidents and fatal accidents during different weather conditions in New Zealand in 2008 (MoT 2009)

Injury accidents					
Light conditions		**Weather condition**			**% in rain**
		Fine	**Heavy rain**	**Light rain**	
Light	Bright sun	4408	4	31	0.79%
	Overcast	2015	59	915	32.59%
Dark	Street lights on	1393	29	425	24.58%
	Street lights off	22	3	6	29.03%
	No. of street lights	732	55	145	21.46%
Total		8570	150	1522	16.32%
Fatal accidents					
Light conditions		**Weather condition**			**% in rain**
		Fine	**Heavy rain**	**Light rain**	
Light	Bright sun	121	-	1	0.82%
	Overcast	30	-	24	44.44%
Dark	Street lights on	34	1	8	20.93%
	Street lights off	-	-	-	-
	No. of street lights	55	4	12	22.54%
Total		240	5	45	17.24%

3.3 Comparisons of driver behaviour in daytime and night-time conditions

The influence of daytime and night-time conditions was examined at all three sites – Kaitoke (a rural 100kph speed zone site), Alexander Drive (a semi-rural 80kph speed zone site), and Fergusson Drive (a well-lit, urban, 50kph speed zone control site).

As with findings in other studies (eg Walton and Thomas 2005) the modal daytime driving hand position was found to be one hand on the top half of the steering wheel. This was observed in all three locations and varied little between the sites (44.7%–47.8%).

Variations between the sites led to some differences in drivers' hand positions. As was established in Walton and Thomas (2005), the speed zone influences hand positions – at the Kaitoke site (a 100kph speed zone), more drivers had two hands on the top half of the steering wheel than was expected, and at the Fergusson Drive site (a 50kph speed zone), we observed fewer hands on the top half of the steering wheel than expected. Examination of the data from the three sites establishes that sites differ during the daytime X^2 (4, N = 1485) = 19.73, $p < .001$). An ordinal-by-ordinal test (Somers' d) indicates that the value of the relationship is weak (d (1485) = -.102, p . <.001), despite being statistically significant.

Against expectation, the aggregated data considering all drivers observed showed no significant difference in hand positions between daytime and night-time driving at the Kaitoke and Alexander Rd sites. The chi-square tests of independence detected no relationship between day-to-night comparisons of hand positions: Kaitoke: X^2 (2, N = 771) = 2.53, p = .28, n.s. Despite being sensitive to even a fairly subtle change in speed (d (1002) = -.071, p.<.016) between an 80km and 100km zone, the method appeared, at first sight, to fail to detect a change in behaviour across a major shift in the visual environment of driving conditions (ie daytime to night-time). We had expected that at night-time, drivers would be more cautious because of the narrowed view of the road corridor and reduced sight distances at the Kaitoke and Alexander Rd sites.

These initial results proved to be a difficult setback in the design and overall aims of the methodology, and led to:

- making additional observations to establish the reliability of night-time observations
- including additional sites, so that we could test the possibility that the existing linemarkings at Kaitoke were of sufficient quality to allow driving behaviours akin to those observed in daylight conditions.

Despite the almost completed abraded linemarkings at the Alexander Rd site, the finding that was observed at Kaitoke was repeated – that is, there was the same sort of driving behaviour whether it was daytime or night-time (see table 3.1 in section 3.1). The repeatability of the night-time measure confirmed that the method was reliable (X^2 (2, N = 259) = 4.872, p = .09, *n.s.*).

The Fergusson Drive site was introduced as a control, to provide a comparison where overhead lighting would ensure a minimal disadvantage for the night-time visual environment. The site was also on a parallel 'back road' alternative to the Alexander Rd site. Once again, driver behaviours (as observed in hand positions) were no different whether it was daytime or night-time (X^2 (2, N = 718) = 1.84, p = .40, *n.s.*) (see table 3.1 in section 3.1). This result further confirmed our previous findings and increased our confidence that the method of observation was sound – the Fergusson Drive site was so well lit that night-vision equipment was not required to make accurate observations (see table 3.5 following)

Against the evidence from all other contexts, where even very minor changes in the road context resulted in a corresponding change in observed hand positions, it appeared that night-time driving was somehow fundamentally different from normal daytime driving.

Table 3.5 Cross tabulation of hand positions, by daytime and night-time conditions for the three observation sites. Fergusson Drive was a 50km zone with overhead lights; Kaitoke was a 100kph zone in a rural area with no street lighting. Significant effects (those with adjusted residuals over 1.96) are highlighted in bold.

Site			Number of hands on top half of steering wheel			Total count
			Zero hands	One hand	Two hands	
Kaitoke	Day	Actual count	105	232	182	519
		Expected count	112.42	232.24	174.35	519
		% hand position	20.23	44.70	35.07	100
		Adjusted residual	-1.38	-0.04	1.24	
	Night	Actual count	62	113	77	252
		Expected count	54.58	112.76	84.65	252
		% hand position	24.60	44.84	30.56	100
	Total count		167	345	259	771

Site			Number of hands on top half of steering wheel			Total count
			Zero hands	One hand	Two hands	
Alexander Rd	Day	Actual count	122	221	140	483
		Expected count	124.40	216.54	142.06	483
		% hand position	25.26	45.76	28.99	100
		Adjusted residual	-0.52	0.85	-0.43	
	Night	Actual count	40	61	45	146
		Expected count	37.60	65.46	42.94	146
		% hand position	27.40	41.78	30.82	100
		Adjusted residual	0.52	-0.85	0.43	
	Total count		162	282	185	629
Fergusson Dr	Day	Actual count	139	231	113	483
		Expected count	145.98	223.34	113.69	483
		% hand position	28.78	47.83	23.40	100
		Adjusted residual	-1.21	1.22	-0.13	
	Night	Actual count	78	101	56	235
		Expected count	71.02	108.66	55.31	235
		% hand position	33.19	42.98	23.83	100
		Adjusted residual	1.21	-1.22	0.13	
	Total count		217	332	169	718

3.3.1 Age as an extraneous factor

A possible explanation of the observed increase in average speed at the Alexander Rd site and the lack of change in hand positions during night-time driving conditions at both Alexander Rd and Kaitoke was that the demographic characteristics of drivers varied between the daytime and night-time. Thus when comparing the conditions, we were breaking a fundamental rule by observing a different population of drivers in the 'before' scenario than in the 'after' scenario (see Hauer 2002 for further explanation).

A broad measure of perceived driver age was collected at the Fergusson Drive site during both daytime and night-time conditions. Driver age was categorised as either 'older' (ie those who looked 60 or more years of age) or 'other' (ie those who looked less than 60 years of age). We observed that older drivers were significantly more likely to drive with two hands on the top half of the steering wheel (X^2 (2, N = 718) = 40.95, $p < .001$) (see table 3.6). More specifically, older drivers were 3.5 times more likely to drive with two hands on the top half of the steering wheel when compared with other drivers (odds ratio = 3.54, CI = 2.36-5.32, $p < .001$).

Table 3.6 Cross tabulation of hand positions, by perceived age group – significant effects (those with adjusted residuals over 1.96) are highlighted in bold

Perceived age group		Number of hands on top half of steering wheel			Total count
		Zero hands	One hand	Two hands	
Other (<60 years)	Observed count	194	286	112	592
	Expected count	178.92	273.74	139.34	592
	% hand position	32.77	48.31	18.92	100
	Adjusted residual	**3.22**	**2.41**	**-6.32**	
Older (60+ years)	Observed count	23	46	57	126
	Expected count	38.08	58.26	29.66	126
	% hand position	18.25	36.51	45.24	100
	Adjusted residual	**-3.22**	**-2.41**	**6.32**	
Total count		217	332	169	718

We observed that older drivers were 2.9 times more common during the day than at night (X^2 (1, N = 753) =19.10, $p < .001$, odds ratio = 2.86, *CI* = 1.76-4.65, $p < .001$) (see table 3.7 below). This low exposure to night-time conditions in older drivers, combined with the fact that older drivers typically place more hands on the top half of the steering wheel, at least partially explains why there was no observed difference between daytime and night-time driver hand positions at Kaitoke or Alexander Rd – ie older drivers may be adapting to a poor visual driving environment at night by limiting their night-time travel. Consequently, there were fewer 'cautious' hand positions observed at night simply because there were fewer older drivers at night.

Table 3.7 Cross tabulation of perceived age group of drivers, by daytime and night-time conditions at Fergusson Drive – significant effects (those with adjusted residuals over 1.96) are highlighted in bold

		Perceived age group		Total count
Fergusson Drive		Other (<60 years)	Older (60+ years)	
Day	Observed count	393	107	500
	Expected count	414.34	85.66	500
	% age group	78.60	21.40	100
	Adjusted residual	**-4.37**	**4.37**	
Night	Observed count	231	22	253
	Expected count	209.66	43.34	253
	% age group	91.30	8.70	100
	Adjusted residual	**4.37**	**-4.37**	
Total count		624	129	753

An examination of New Zealand Household Travel Survey data (MoT 2006) supports this age finding, revealing that drivers aged 60 or more years are significantly more likely to be driving in the mid-afternoon, and significantly less likely to be driving later at night, when compared with drivers aged under 30 years (X^2 (16, N = 14,532) = 312.73, $p < .001$) (see table 3.8).

Table 3.8 Cross tabulation of motor vehicle travel time, by age group (data from MoT 2006). Significant effects (those with adjusted residuals over 1.96) are highlighted in bold.

Age group		Hour of day									Total count
		3pm	4pm	5pm	6pm	7pm	8pm	9pm	10pm	11pm	
15–29	Observed count	462	498	620	482	293	241	200	127	81	3004
	Expected count	644	593	643	411	272	163	135	88	55	3004
	Adjusted residual	**-9.09**	**-4.87**	-1.13	**4.24**	1.50	**7.04**	**6.38**	**4.76**	**3.94**	
30–59	Observed count	2034	1787	2034	1265	856	451	369	228	163	9187
	Expected count	1970	1812	1965	1257	832	499	414	269	169	9187
	Adjusted residual	**2.69**	-1.10	**2.87**	0.41	1.44	**-3.63**	**-3.74**	**-4.15**	-0.74	
60+	Observed count	620	582	455	241	167	97	86	70	23	2341
	Expected count	502	462	501	320	212	127	106	68	43	2341
	Adjusted residual	**6.49**	**6.81**	**-2.52**	**-5.20**	**-3.54**	**-3.00**	**-2.12**	0.21	**-3.36**	
Total count		3116	2867	3109	1988	1316	789	655	425	267	14,532

3.4 Effect of improved delineation on driver behaviour

The delineation on the Alexander Rd site was upgraded to increase the retroreflectivity from 38Rl to 142Rl. The visible change can be seen in figure 3.2, where there is a clear improvement in retroreflectivity in the 'after' photographs. The 'before/after' design of this research ensured that other contaminating factors, such as the demographic characteristics of the drivers, the speed zone and the road conditions, were controlled.

Figure 3.2 Linemarkings before (left) and after (right) an upgrade

Visibility software (developed by the European COST) was used to calculate preview times and sight distances of the road under each night-time condition. Table 3.10 outlines the sight distances and preview times by headlight condition (dipped or full beam) and age group for Alexander Rd (before and after), for Kaitoke, and for a recommended (100Rl) site (to illustrate the comparison). Only at very low retroreflectivity levels (38Rl) and in the older age group (76–85 years) do the preview times reach the 1.8 seconds recommended as the minimum for safe road negotiation by COST (1999). The roadmarking upgrade made an average improvement to preview time of about 1.6 seconds, or an average improvement to sight distance of about 35 metres (depending on the age group and headlight condition).

Table 3.10 The sight distances and preview times of roadmarkings in night-time conditions, by site and by headlight condition

		Alexander Rd (vehicles travelling at 71kph)				Kaitoke (vehicles travelling at 91kph)			
		Before upgrade (38Rl)		After upgrade (142Rl)		220Rl		Minimum recommended (100Rl)	
Headlight condition	**Driver age group**	**Preview time (s)**	**Sight distance (m)**	**Preview time (s)**	**Sight distance (m)**	**Preview time (s)**	**Sight distance (m)**	**Preview time (s)**	**Sight distance (m)**
Dipped headlights	16–25	2.8	65	4.1	91	4.0	100	3.9	87
	26–35	2.8	62	4.1	90	3.9	98	3.9	86
	36–45	2.8	62	4.0	89	3.8	97	3.8	85
	46–55	2.7	60	4.0	88	3.8	95	3.7	83
	56–65	2.6	58	3.9	86	3.6	92	3.6	81
	66–75	2.3	51	3.6	79	3.4	86	3.3	74
	76–85	1.8	39	2.9	64	2.8	72	2.7	59
Full headlights	16–25	3.1	68	5.3	117	5.4	136	4.8	106
	26–35	3.0	66	5.1	114	5.3	133	4.6	103
	36–45	2.9	65	5.0	112	5.1	130	4.5	101
	46–55	2.8	62	4.8	107	4.9	125	4.4	97
	56–65	2.7	60	4.6	102	4.7	119	4.2	93
	66–75	2.3	52	4.0	89	4.1	103	3.6	80
	76–85	1.8	39	3.0	66	3.0	77	2.7	60

Before the upgrade, night-time drivers were observed to be about twice as likely (odds ratio = .54, *CI* = 0.30-0.97, $p < .05$) to place both their hands on the top half of the steering wheel, indicating a higher level of perceived risk (X^2 (1, N = 259) = 4.28, $p < .05$). Arguably, drivers perceived that the new linemarkings made a significant improvement to their driving environment at night (see table 3.11). As expected, no significant change was observed in hand positions before and after the upgrade during the day-time condition (X^2 (1, N = 968) = 1.10, $p > .05$). However, after the improvement in linemarking retroreflectivity there was a shift in hand positions, with around a third of the drivers who had normally been observed with a 'two-hand' configuration using a lower, more relaxed pattern of hand positions. This shift represented a change of about 37% away from the use of the cautious hand position – that is, the effect of the reflectivity improvement could be quantified as a 37% improvement towards daytime conditions.

Table 3.9 Cross tabulation of night-time hand positions before and after a roadmarking upgrade – significant effects (those with adjusted residuals over 1.96) are highlighted in bold

Alexander Rd night		Hand position		Total count
		Other	Two hands	
Before upgrade (38Rl)	Observed count	101	45	146
	Expected count	108.23	37.77	146
	% hand position	69.18	30.82	100
	Adjusted residual	**-2.07**	**2.07**	
After upgrade (142Rl)	Observed count	91	22	113
	Expected count	83.77	29.23	113
	% hand position	80.53	19.47	100
	Adjusted residual	**2.07**	**-2.07**	
Total count		192	67	259

3.4.1 The effect of improved delineation on speed and headway

Research into perceptual countermeasures indicates that the width of the road influences driver speeds, with wider roads being related to higher speeds (Godley et al 2004, Lewis-Evans and Charlton 2006).

As shown in table 3.10, the improved delineation in this case had the effect of *reducing* vehicle speed during the daytime – possibly because when the roadmarkings were poor, the lane was perceived by drivers to be wider than it actually was, and once the markings were improved, the actual lane widths became obvious.

Table 3.10 Descriptives and significant differences for speed and headway before and after a roadmarking upgrade

Variable	Light condition	Roadmarking condition								
		Before upgrade (38Rl)			After upgrade (142Rl)					
		N	M	SD	N	M	SD	t	p	
Speed	Day	406	73.65	6.27	254	71.85	8.04	3.22	0.001	***
	Night	151	75.50	9.61	130	74.20	9.63	1.13	0.261	
Headway	Day	168	1.98	0.75	74	1.85	0.68	1.28	0.201	
	Night	9	2.00	0.87	20	1.90	0.64	0.35	0.730	

Note: *** = p < .001

4 Discussion and conclusions

The effect of road delineation on drivers has previously defied examination by researchers. In particular, the relationship between variations in the quality of roadmarkings and actual driving performance has not been well understood. However, it is obvious that even roads without any linemarkings can be negotiated well if a driver adjusts their driving behaviours to meet the conditions. These changes in behaviour should be observable, but traditional measures have failed to quantify them. This has hampered the work of road asset managers who seek to optimise the road network's performance and assess new materials that are designed to assist drivers at night-time and in wet conditions.

In this research project, a conceptually complex but practically straightforward technique was used to determine the effect of linemarkings when comparing night-time driving behaviours with the baseline of daytime driving behaviours. This study has revealed a successful, reliable method, which is more sensitive than speed or headway, of quantifying the benefits of road delineation improvements.

The data showed that an improvement in linemarking retroreflectivity (from 38Rl to 142Rl) resulted in a shift in behaviours that were representative of those observed in daytime conditions. Where the roadmarkings were bright (rather than worn), night-time drivers were about twice as likely to adopt a steering wheel hand-position configuration similar to that used in daylight conditions (ie a more relaxed hand position) – about 11% fewer drivers had two hands on the top half of the steering wheel. This change in driver behaviours represented a quantification of the effect of the 106RI improvement in the linemarking – ie a 37% improvement in driver behaviours between the old markings (38RI) and the new markings (142RI). Clearly, the nature of the relationship between linemarkings' physical characteristics and improvement in driver behaviours cannot be determined by a single site observation, but this result has established that the method used in this study can be used to measure that relationship.

Discussion of the specific findings regarding the influence of linemarkings under the wet night-time conditions, and improved delineation conditions, follows. In each of these conditions, comparisons were made with driver behaviour under the dry daytime condition (at each site), as this condition was assumed to provide the best-possible visual environment. The performance of the roadmarkings was therefore assessed against whether they replicated a visual environment that was as good as the dry daytime visual environment.

4.1 Wet conditions

Wet conditions elicited the highest level of apparent perceived risk, with 53% of drivers adopting a '10 to 2' hand position – this was the highest recorded proportion of drivers with this hand position to date across any of the previous studies of hand positions (Walton and Thomas 2005, Thomas and Walton 2007, Fourie et al, *in press*). When compared with dry daytime or dry night-time conditions at the same site, drivers were 2–2.5 times more likely to adopt a '10 to 2' hand position in wet conditions. In addition, drivers concurrently adjusted their speeds to about 9kph slower in the wet conditions, but despite this, they still increased the security of their hand positions (cf Walton and Thomas 2005, who found that reduced speed led to more relaxed hand positions).

These findings implicated exposure to wet conditions as a leading cause of visibility reduction while driving. McKnight et al (1998) suggested that the only time roadmarking line width and contrast had a substantial effect upon lane-keeping was when there was an extremely low level of contrast between the roadmarking and the road surface, such as in wet night-time conditions. In a meta-analysis examining the influence of adverse weather conditions on crash risk, wet weather was found to increase accident risk by

71% (Qiu and Nixon 2008). Motor vehicle accidents involving wet weather made up approximately 16% of injury accidents and 17% of fatal accidents in New Zealand in 2008 (MoT 2009).

Andrey and Yagar (1993) also found that accident risk during rainfall conditions was approximately 70% higher than in other conditions. However, the increase in risk was eliminated as soon as the rainfall ceased, even though the wet conditions of the road remained. The key elements of the visibility issue were considered to be a reduction in vision because of the interference of rain hitting the vehicle windscreen and from light reflecting off the falling rain. It is important to note that the current methods for measuring linemarking retroreflectivity can take into account the influence of precipitation on the actual roadmarking, but it does not measure the level of reduction in sight distance that is caused by rainfall.

Roadmarking standards and interventions need to focus on providing better sight distances during rainfall conditions, and this is not limited to just providing good retroreflectivity when roadmarkings are wet. The assessment of wet-weather roadmarkings should be tested in a real-world environment, as any replication of the conditions in a simulated environment is likely to have poor ecological validity.

4.2 Night-time conditions

Initially, there was no detectable difference in hand-position configurations between night-time and daytime conditions across all three sites, despite very large differences between the delineation treatments at the different sites (well-maintained linemarkings, poor linemarkings, and overhead lighting). Repeated night-time observations confirmed, and re-confirmed, these results, which seemed to be counter-intuitive.

Expanding the number of sites to three and repeating the observations eliminated the possibility of having a methodological confound due to the method of observation at night. Using night-vision equipment was technically challenging and arguably at the limits of available technology. It was difficult to observe the inside of a moving vehicle at night, especially when it was travelling at 80–100kph. In particular, it was difficult to observe the position of the driver's left hand, as it was further into the darkened interior of the vehicle. If true, this explanation would have undermined our experiment, as we would be systemically under-reporting the night-time incidence of the two-hands position and the one-hand position (particularly when it was the left hand that was on the steering wheel).

Nonetheless, night-time observations at the 50kph zone with overhead lighting (the Fergusson Drive site) resulted in the same finding – ie no change between daytime and night-time hand-pattern configurations.

The logical difficulty was that the improvement in lighting that allowed us to not use the night-vision equipment also allowed drivers to drive as if it was daylight and adopt a daytime driving hand position. However, the findings of all the sites taken as a whole ruled out that explanation. When the linemarkings at the Alexander Rd site were upgraded, there was a difference in the hand positions being adopted. In addition, we found that the overall demographics of drivers co-varied with the time of the observations, and these differences matched with the expected variation in hand positions – ie the reduction in the number of older drivers at night-time appeared to be responsible for the lack of difference in the hand-position configurations observed at night. This trend was further understood and confirmed by examining National Household Travel Survey data (MoT 2006).

These demographic changes confounded measurement of the condition changes. Despite the more difficult driving conditions and consequently higher perception of risk at night, the reduction in the number of older drivers (who tend to have relatively higher perceptions of risk overall) meant the overall pattern of driving behaviour matched the pattern observed in daytime conditions. In the broad sense, we observed an ecological version of risk homoeostasis (Wilde 1982) – ie drivers as a group (vis-a-vis individuals) maintain a level of risk that is matched against their perceptions of conditions.

The implication of these findings is that drivers do adapt to the reduced visual conditions of night-time driving, and that the visual environment could be improved at great benefit to drivers. Suh et al (2006) also found that drivers adapted to their environment at night, maintaining greater visual focus on the road than they did in daylight conditions. The idea that drivers who are visually limited (eg older drivers) avoid driving in poor visibility conditions is just an extension of this adaptation.

As an aside, this adaptation may also prevent older drivers from accessing the full range of social activities that are available to other drivers. It is not known whether the reason for the avoidance of night-time travel is because of a poor visual environment, or simply because older people do not need to travel at night. If the former, then improved road delineation could lead to arguably greater benefits, such as greater social inclusion, than have previously been investigated or understood. It is clear, however, that a benefit afforded by good road delineation is the ability to travel comfortably at night and this functionality is not currently used by all road users.

4.3 Improved delineation

This study showed that improved road delineation resulted in a significant reduction in the number of hands placed on the top half of the steering wheel at night. This was considered reasonable evidence that the driver was detecting a measurable improvement in the visual environment and was consequently more relaxed when driving at night. The finding that there was no detectable difference in hand-position configurations after the upgrade for the daytime condition further confirms the theory that night-time driving is more difficult, and that improved roadmarkings provide detectable benefits to drivers at night.

The improved road delineation that we examined created conditions that made night-time driving conditions comparable to daytime driving conditions, which means that it is possible to create an improved visual environment at night without the expense of lighting solutions (ie streetlights), and to measure such.

Previous findings regarding the relationship between retroreflectivity and driver behaviour may have been inconclusive because of the insensitivity of measures such as monitoring vehicle speeds. In this study, the other measures, such as vehicle speeds and headways, did not change significantly at night after the linemarkings upgrade. The ‘hands-on’ measure was more sensitive than other intermediate measures of perceived driver risk.

This study did not examine enough sites to establish the relationship between improvements to retroreflectivity and improved driver behaviour (relative to daytime driving behaviour). However, our results could be used to illustrate the type of result that could be obtained, using the method presented here, in examination of further sites of upgraded linemarkings. For example, if the relationship between hand position and retroreflectivity was linear for the Alexander Rd upgrade, the improvement in retroreflectivity of 104Rl led to an approximate 11% reduction in ‘tense’ hand positions (ie hands positioned at ‘10 to 2’), which equates to 1% of the drivers perceiving a level of visibility comparable to daytime conditions for every 9Rl of retroreflectivity improvement. It is important to note that the relationship is not likely to be linear; improvements will have diminishing returns as retroreflectivity increases. At the higher levels, increased retroreflectivity could result in increased glare and become an impediment in the driver’s visual field.

4.4 The benefit of the 'hands-on' method

The 'hands-on' method is sensitive to improvements or changes in road delineation. The method has been reliably tested in night-time driving environments, and it can now be used to determine the nature of the relationship between improvements in road delineation, and to assess the benefits by the degree to which drivers' behaviours change towards daytime behaviours. This method could lead to a re-evaluation of the *Manual of traffic signs and markings (MOTSAM)* (NZTA 2010) and the *Road and traffic standard 5: guidelines for rural road marking and delineation (RTS-5)* (MoT 1992) regarding:

1 the minimum level of service of delineation that is appropriate to the road conditions

2 the maintenance thresholds at which roadmarkings should be upgraded

3 the evaluation of supplemental visibility devices (eg edge-marker posts or cat's eyes).

New Zealand road authorities can use the successfully tested, sensitive 'hands-on' observation method to ensure that the materials and delineation practices being used are effective. The evidence from this study confirms that the 'hands-on' method can assess the effectiveness or redundancy of different delineation treatments more effectively than other intermediate measures of risk (eg speed and headway). We found the following advantages:

- **Sensitivity:** The 'hands-on' method provides a more sensitive baseline from which to evaluate intervention effectiveness when compared with common measures (eg speed and headway data). This sensitivity derives from the fact that hand positions are not restricted by external regulatory constraints or social norms. Before/after studies of interventions to the road corridor that have revealed no significant changes in speed may still reveal a change in hand-position configurations.
- **Immediacy:** The 'hands-on' method provides the ability to measure driver behaviour immediately after an intervention, without sole reliance on the change to accident rates over time, which requires a longer time period to provide any reliability.
- **Reliability and validity:** The 'hands-on' measure is consistently reliable within different environmental contexts and over time, and also achieves face validity, as drivers believe that their hand positions do change depending on the level of risk they perceive in the driving environment.

The measure is potentially sensitive enough to detect small variations in hand positions as a response to relatively minor changes in the visual environment (such as the presence of a newly placed road cone). It was not a requirement of this project to examine the full potential of the method. Rather, the method was applied to the seemingly intractable problem of assessing how people respond to changes in the visual environment as it is altered by improvements in road delineation treatments.

4.4.1 Limitations

It was hard to get very high inter-rater reliability in rainy conditions, as observations were typically made through the drivers'-side windows of passing vehicles, which were partially beaded with rain. It is possible that a better observation set up and some practice would overcome this problem.

An ideal test would have established the influence of wet night-time conditions – however, night-time hand-position data was not collected in rainy weather because rain prevented night-vision equipment, particularly projected infrared light, from working effectively. The night-vision equipment was very responsive to the ambient light reflecting from the rain, and this scattered the image. The rain caused much more light to go toward the night-vision unit and degraded its performance so much that getting a clear view of drivers' hand positions was not possible.

4.5 Future research

Future research examining the effect of alterations to the road environment on driver behaviour will benefit from the use of the 'hands-on' method. Outlined below are:

- a study that will specifically quantify the benefits of improving the retroreflectivity of roadmarkings
- a broader study designed to improve the overall design of the road corridor.

4.5.1 Quantifying the benefits of improved retroreflectivity

The quantification of the benefits of improved roadmarkings can be modelled to establish the threshold at which night-time road delineation mimics dry daytime (ideal) visual driving conditions. Modelling the relationship between daytime/night-time changes in relative hand positions after different increments of improvement in retroreflectivity (across multiple roadmarking interventions) would provide an evidence base to determine a minimum required retroreflectivity level. This study would also benefit from the inclusion of reduced-visibility conditions (such as rain), to ensure the minimum standards were a conservative test of retroreflectivity.

The importance of delivering a method that accurately quantifies the benefit of improved roadmarking retroreflectivity becomes apparent when the cost involved in the application and maintenance of roadmarkings is examined. The current cost of roadmarkings in New Zealand is approximately $40–50 million per annum (Dravitzki 2010, pers comm).

As well as increasing driver comfort, a better night-time visual environment may also reduce driver fatigue. Liu and Wu (2009) found that fatigue caused by driving in a complex environment has a negative impact on driving performance and visual-performance tasks. For example, maintaining lane position on a road with a longer sight distance is likely to be less fatiguing over time.

4.5.2 Self-explaining roads

The hand-position measure (in combination with other known behavioural measures, such as speed) can be used as general measure of road network performance, to determine how intuitively the design of the road environment aligns with driver expectations – ie the concept of self-explaining roads (Kaptein and Claessens 1998). Such roads are thought to reduce accidents by up to 50% (Hassan and Easa 2003, Heger and Schlag 2003).

At the broadest level, the performance of different sections of the road network could be examined relative to behaviour that is 'typical' of that driving environment. For example, the earliest work examining the 'hands-on' measure found a baseline composition of hand positions on the top half of the steering wheel of 25% zero hands, 50% one hand and 25% two hands (Walton and Thomas 2005). 'Typical' hand positions could be classified according to broad factors such as road type and speed zone. Sites identified as significantly different from the standard hand position observed for that road category could then be identified as problematic.

4.6 A practical guide to using the hand-position measure

The 'hands-on' method can be easily used by road safety practitioners. The following guide has been created to provide some useful tips based on the lessons that have been learnt while testing this method in the field.

4.6.1 Practical uses

The hand-position measure can be used in the before/after evaluation of any design for any visual or environmental feature in the road corridor. Circumstances in which the 'hands-on' method will be particularly useful include the evaluation of:

- improved or new signage – including changes in driver behaviour both before and after the variable message signs (VMS) are installed
- purposive perceptual countermeasures – such as roadmarkings that make the lanes narrower, and other perceptual speed interventions
- the effect of alterations to the road delineation – such as alterations to roadmarkings, edge-marker posts or cat's eyes.

4.6.2 Methodological tips

There are several anecdotal tips for the successful collection of hand-position data:

- Typically, two hours of data should be collected for each condition – but this will depend on Average Annual Daily Traffic (AADT) levels and the time of day.
- The level of accuracy required between the two observers is typically around 90% or above (see section 3.1 'Driver observations'). Training of observers should occur until observer consistency is ensured at a minimum of this 90% level (preferably higher). It is also recommended that the first 10 observations at each site should be checked after they are collected to ensure consistency of categorisation. Common sources of misclassification occur when a driver's hands are partially on the steering wheel, when a driver shifts their hand position at the point of observation, and when a hand is placed close to the bottom of the steering wheel.
- Both observers should be situated close together, so that they have a similar visual angle of each driver at the same time.
- Not every driver hand position needs to be collected. Collecting driver hand positions is a very demanding task when there is a platoon of vehicles following closely to one another. To ensure that both observers are examining the same drivers, it helps if one observer calls out the vehicles to be examined (preferably based on some predefined rules, so that there is no systematic bias in the sampling process). Also, sequentially numbering the observations ensures that both observers are making matched observations of the same drivers (in case one observer misses a vehicle). Sometimes it will make sense simply to collect the first vehicle in a platoon; at other times the interest might be related to drivers' dealings with the car in front of them.
- The use of technology, such as video or still photography, to capture hand positions was found to be cumbersome, but is achievable in daylight. A high-speed camera can get a good picture of the hand positions. While the ability of a human eyewitness was preferable to the technology we examined, there are obvious benefits to technological solutions that collect continuous hand-position data remotely.
- The 'target' window of time that offers the best observations of driver hand-position observations appears to be from when the vehicle is perpendicular to the observer through to when the vehicle is just past the observer (at about a 20-degree angle).

Anecdotal evidence suggested that hand-position observations were made easier by:

- slower speed zones

- dry conditions
- vehicles without tinted windows
- an elevated view for observers (looking down into the vehicle cab)
- a driver's-side view of the vehicle
- using the steering-wheel design (where appropriate) as a visual cue – most modern steering wheels have a horizontal bar going through them that meets the circular frame of the steering wheel either at, or just below, the '9 o'clock' and '3 o'clock' positions. Hands positioned above the bar are likely to be in the target zone.

5 Recommendations

1 Delineation solutions for wet conditions should be given more priority than solutions for night-time conditions, because wet conditions create the most difficult visual driving environment. This recommendation is based on the evidence that even in the daytime, drivers were 2.5 times more likely to place two hands on the top half of the steering wheel when it was raining, compared with night-time conditions.

2 The relationship between retroreflectivity and hand positions can now be modelled, using multiple sites with different increments in retroreflectivity, to determine the relationship between improvement in retroreflectivity and its effect on drivers.

3 Before/after assessments of engineering interventions to improve the road corridor can, with confidence, include observations of intermediate measures such as hand position to determine the effects of changes on drivers. To the extent that the hands-on measure is a more sensitive measure of driver risk than speed or headway, it can be used as a more subtle measure of changes in drivers' perceived risk.

4 The 'hands-on' method measured an unexpected but very significant reduction in night-time driving by older people. This effect needed to be controlled for in the present study, and should be investigated separately. It was beyond the scope of this research to determine the extent to which effective road delineation could affect general driving behaviour in a specific sector of the community. However, further research could examine the improved social/travel opportunity outcomes for older drivers that would result from an improved night-time driving environment.

6 References

Andrey, J and S Yagar (1993) A temporal analysis of rain-related crash risk. *Accident Analysis and Prevention 25*, no.4: 465–472.

Charlton, SG (2003) Restricting intersection visibility to reduce approach speeds. *Accident Analysis and Prevention 35*: 817–823.

Cohen, J (1960) A coefficient of agreement for nominal scales. *Educational and Psychological Measurement 20*: 37–46.

Colbourn, CJ (1978) Perceived risk as a determinant of driver behaviour. *Accident Analysis and Prevention 10*: 131–141.

Debaillon, C, PJ Carlson, HG Hawkins, Y He, T Schnell and F Aktan (2008) Review and development of recommended minimum pavement marking retroreflectivity levels. *Transportation Research Record 2055*: 71–77.

Dejoy, DM (1992) An examination of gender differences in traffic accident risk perception. *Accident Analysis & Prevention 24*: 237–46.

Donnell, ET, V Karwa and S Sathyanarayanan (2009) Analysis of effects of pavement marking retroreflectivity on traffic crash frequency on highways in North Carolina: application of artificial neural networks and generalized estimating equations. *Transportation Research Record 2103*: 50–60.

Dravitzki, VK, SM Wilkie and TJ Lester (2006) The safety benefits of brighter roadmarkings. *NZ Transport Agency research report 310*: 43pp.

Evans, L (2004) *Traffic safety.* Michigan: Science Serving Society.

Evans, L and P Wasielewski (1983) Risky driving related to driver and vehicle characteristics. *Accident Analysis and Prevention 15:* 121–136.

European Co-operation in the Field of Scientific and Technical Research (1999) *COST 331: Requirements for horizontal road marking.* Luxembourg: European Communities.

Fourie, MK (2008) A risk worth taking? An examination of driver hand position as a risk-taking behaviour. Unpublished thesis: University of Canterbury, Psychology Department.

Fourie, MK, D Walton and JA Thomas *(In press*) Evaluating driver hand positions as a measure of perceived risk. Transportation Research Part F.

Glendon, A (2007) Driving violations observed: an Australian study. *Ergonomics 50:* 1159–1182.

Godley, ST (1999) A driving simulator investigation of perceptual countermeasures to speeding. PhD Thesis: Monash University. Accessed 10 June 2008. *www.psych.usyd.edu.au/staff/stuartg/GodleyThesis.pdf*

Godley, ST, TJ Triggs and BN Fildes (2004) Perceptual lane width, wide perceptual road centre markings and driving speeds. *Ergonomics 47,* no.3: 237–256.

Hassan, Y and SM Easa (2003) Effect of vertical alignment on driver perception on horizontal curves. *Journal of Transportation Engineering 129*: 399–407.

Hauer, E (2002) *Observational before–after studies in road safety: estimating the effect of highway and traffic engineering measures on road safety.* New York: Pergamon.

Heger, R and B Schlag (2003) Driver perception of roadway, traffic and environment: a basic human factor to be considered in road design standards. In *Proceedings of the XXIInd PIARC World Road Congress*, Durban, South Africa.

Horberry, T, Anderson, J and MA Regan (2006) The possible safety benefits of enhanced road markings: a driving simulator evaluation. *Transportation Research Part F 9*: 77–87.

Horvath, P and M Zuckerman (1993) Sensation seeking, risk appraisal, and risky behaviour. *Personality and Individual Differences 14:* 41–52.

Johansson, O, PO Wanvik and R Elvik (2009) A new method for assessing the risk of accident associated with darkness. *Accident Analysis and Prevention 41:* 809–815.

Jonah, BA (1990) Age differences in risky driving. *Health Education Research: Theory and Practice 5:* 139–149.

Jonah, BA (1997) Sensation seeking and risky driving: a review and synthesis of the literature. *Accident Analysis and Prevention 29*: 651–665.

Kaptein NA and M Claessens (1998) *Effects of cognitive road classification on driving behaviour: a driving simulator study,* (MASTER deliverable 5). Finland: VTT Communities and Infrastructure. 47pp.

King, G, RO Keohane and S Verba (1994) *Designing social inquiry: scientific inference in qualitative research*. Princeton, NJ: Princeton University.

Kline, TL (2001) Developing efficient steering techniques. *The Chronicle of the American Driver and Traffic Safety Education Association, 49*, no.2. Indiana University of Pennsylvania, Indiana, PA.

Konstantopoulos, P, P Chapman and D Crundall (2010) Driver's visual attention as a function of driving experience and visibility. Using a driving simulator to explore drivers' eye movements in day, night and rain driving. *Accident Analysis and Prevention 42*: 827–834.

Land, MF and DN Lee (1994) Where we look when we steer. *Nature 369* (6483): 742–744.

Lewis-Evans, B and SG Charlton (2006) Explicit and implicit processes in behavioural adaptation to road width. *Accident Analysis and Prevention 38*: 610–617.

Liu, Y and T Wu (2009) Fatigued driver's driving behaviour and cognitive task performance: effects of road environments and road environment changes. *Safety Science 47*: 1083–1089.

Lombard, M, J Snyder-Duch and CC Bracken (2008) Practical resources for assessing and reporting intercoder reliability in content analysis research projects. Accessed 16 January 2009. *http://astro.temple.edu/~lombard/reliability/*

Lund, AK and B O'Neill (1986) Perceived risks and driving behaviour. *Accident Analysis and Prevention 18*: 367–370.

Masliah, M, G Bahar and E Hauer (2007) Application of innovative time series methodology to relationship between retroreflectivity of pavement markings and crashes. *Transportation Research Record 2019*: 119–126.

Metcheck (2010) Glossary of terms. Accessed 16 March 2010. *www.metcheck.com/V40/UK/OTHER/glossary.asp*

McKnight, AS, AJ McKnight and AS Tippetts (1998) The effect of lane line width and contrast upon lanekeeping. *Accident Analysis and Prevention 30*, no.5: 617–624.

Ministry of Transport (MoT) (1992) Road and traffic standard 5: guidelines for rural road marking and delineation (RTS-5). Accessed 12 December 2009. *www.nzta.govt.nz/resources/road-traffic-standards/docs/rts-05.pdf*

Ministry of Transport (MoT) (2006) New Zealand Household Travel Survey data. Accessed 12 December 2009. *www.transport.govt.nz/research/travelsurvey*

Ministry of Transport (MoT) (2009) Motor vehicle crashes in New Zealand 2008. Accessed 12 December 2009. *www.transport.govt.nz/research/MotorVehicleCrashesinNewZealand2008*

National Institute of Water & Atmospheric Research (NIWA) (2010) Climate summaries. Accessed 16 March 2010. *www.niwa.co.nz/education-and-training/schools/resources/climate/summary*

Nunnaly, J (1978) *Psychometric theory.* New York: McGraw-Hill.

NZ Transport Agency (2010) Manual of traffic signs and markings (MOTSAM). Accessed 12 December 2010. *www.nzta.govt.nz/resources/motsam*

NZ Transport Agency (2010) *The official New Zealand road code*. Wellington: NZ Transport Agency.

Palamara, P and MR Stevenson (2003) *A longitudinal investigation of psychosocial risk factors for speeding offences among young motor car drivers.* Data report PR128. Crawley, Western Australia: Injury Research Centre.

Paris, H and S van den Broucke (2008) Measuring cognitive determinants of speeding: an application of the theory of planned behaviour. *Transportation Research Part F, 11*: 168–180.

Parker, D, L McDonald, P Sutcliffe and P Rabbitt (2001) Confidence and the older driver. *Ageing and Society 21*: 169–182.

Qiu, L and WA Nixon (2008) Effects of adverse weather on traffic crashes: systematic review and meta-analysis. *Transportation Research Record 2055*: 139–146.

Rundmo, T and H Iverson (2004) Risk perception and driving behaviour among adolescents in two Norwegian counties before and after a traffic safety campaign. *Safety Science 42:* 1–21.

Sanders, MS (1981) Peak and sustained isometric forces applied to a truck steering wheel. *Human Factors, 23*, no.3: 655–66.

Suh, W, PY Park, CH Park and KS Chon (2006) Relationship between speed, lateral placement, and drivers' eye movement at two-lane rural highways. *Journal of Transportation Engineering 132,* no.8: 649–653.

Thomas, JA and D Walton (2007) Measuring perceived risk: self-reported and actual hand positions of SUV and car drivers. *Transportation Research Part F, 10*: 201–207.

Ulleberg, P and T Rundmo (2003) Personality, attitudes and risk perception as a predictor of risky driving behaviour among young drivers. *Safety Science 42*: 427–443.

Van Driel, CJG, RJ Davidse and MFAM van Maarseveen (2004) The effects of an edgeline on speed and lateral position: a meta-analysis. *Accident Analysis and Prevention 36*: 671–682.

Van Vliet, P and G Schermers (2000) *Sustainable safety: a new approach for road safety in the Netherlands.* Rotterdam: Traffic Research Centre.

Walton, D and JA Thomas (2005) Naturalistic observations of driver hand positions. *Transportation Research Part F, 8*: 229–238.

Wasielewski, P (1979) Car-following headways on freeways interpreted by the semi-Poisson headway distribution model. *Transportation Science 13*, no.1: 36–55.

Wilde, GJS (1982) The theory of risk homeostasis: implications for safety and health. *Risk Analysis 2*: 209–225.

Wilde, GJS (1988) Risk homeostasis and traffic accidents: propositions, deductions and discussion on recent commentaries. *Ergonomics 31*: 441–468.

Wilde, GJS (1997) Risk homeostasis theory: an overview. In *Proceedings of the National Driver and Awareness Conference*, November 1997, Wellington, New Zealand.

Zuckerman, M (1979a) *Sensation seeking: beyond the optimal level of arousal.* Hillsdale, NJ: Erlbaum.

Zuckerman, M (1979b) Sensation seeking and risk taking. Pp163–197 in *Emotions in personality and psychopathology*. CE Izard (Ed). New York: Plenum.

Zuckerman, M (1983) *Biological bases of sensation seeking, impulsivity and anxiety*. Hillsdale, NJ: Erlbaum.

Zuckerman, M (1994) *Behavioural expressions and biosocial bases of sensation seeking*. New York: Cambridge University Press.

Appendix A Driver survey

OPUS
INTERNATIONAL CONSULTANTS

Driver Behaviour Survey

For Information Contact
Martin Fourie: Ph 0272239666 or email mkf21@student.canterbury.ac.nz
or
***Darren Walton:* *Ph 04 5870663* or email darren.walton@opus.co.nz**
Freepost 159581, Opus Central Laboratories, PO Box 30845, Lower Hutt

What this survey is about
The purpose of this survey is to gain a better understanding of driver behaviour and the extent to which driver behaviour can signal drivers' risk perception. The study is being conducted as part of a University of Canterbury Masters Degree.

IMPORTANT POINTS

1. ***We value your opinion***
2. ***If a question doesn't make sense then let us know, but try to answer by choosing the most appropriate response***
3. ***We will not ask you to identify yourself for the survey, so your answers are entirely confidential***
4. ***You may withdraw your participation at any point***

This survey should take about** [Needs to be piloted] **minutes

Driver Gender *[please indicate you gender by ticking the appropriate box]*	**Male**	**Female**
1. Gender	☐	☐

Driver Exposure
[please answer the following questions to the best of your ability]

1. **How many years have you been driving motor vehicles?**

☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
0-3 years	4-7 years	8-11 years	12-15 years	16-19 years	20-23 years	24-27 years	28-31 years	32-35 years	More than 35 years

2. **How many years have you had your full drivers licence for?**

☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
0-3 years	4-7 years	8-11 years	12-15 years	16-19 years	20-23 y ears	24-27 years	28-31 years	32-35 years	More than 35 years

3. **A typical privately owned motor vehicle would travel about 14,000 kilometres each year. Please estimate how far you travel in your private motor vehicle each year**

	☐	☐	☐	☐	☐
Travel distance per year	Much Less	Slightly Less	About the same	Slightly More	Much More

The following section relates to your attitudes to driving and other drivers. This section is important as it lets us understand the motivations and desires that influence your driving behaviour. Some of the statements may relate to other areas of your life, these statements are relevant as they give us better insight when trying to understand your general perspective on life. If you feel that any of the statements are overly personal just skip them and move on to the next statement.

Driver Safety *[please complete the sentences by ticking the most appropriate box]*	Much Less Safe	Somewhat Less Safe	Equally Safe	Somewhat Safer	Much Safer
4. My driver safety relative to other drivers my age and sex is	☐	☐	☐	☐	☐
5. My driver safety relative to the average motorist is	☐	☐	☐	☐	☐
Driver Skill *[please complete the sentences by ticking the most appropriate box]*	Much Less Skilful	Somewhat Less Skilful	Equally Skilful	Somewhat more Skilful	Much more Skilful
6. My driver skill relative to other drivers my age and sex is	☐	☐	☐	☐	☐
7. My driver safety relative to the average motorist is	☐	☐	☐	☐	☐
Accident Likelihood *[please complete the sentences by ticking the most appropriate box]*	Much Less Likely	Somewhat Less Likely	Equally Likely	Somewhat more Likely	Much more Likely
8. My likelihood of being in a motorcar accident relative to drivers my age and sex is	☐	☐	☐	☐	☐
9. My likelihood of being in a motorcar accident relative to the average motorist is	☐	☐	☐	☐	☐

Accident Potential *[please tick the box you feel best describes the likelihood the behaviour may result in an accident]*	Highly Unlikely	Fairly Unlikely	Neutral	Fairly Likely	Highly Likely
10. Exceeding the posted speed by between 20 - 30 km/h	☐	☐	☐	☐	☐
11. Failing to give way to pedestrians at a zebra crossing	☐	☐	☐	☐	☐
12. Driving excessively fast in conditions of limited visibility	☐	☐	☐	☐	☐
13. Driving without fastening one's seat belt	☐	☐	☐	☐	☐
14. Driving with a blood alcohol level slightly above the legal limit	☐	☐	☐	☐	☐
15. Failing to give way to another vehicle	☐	☐	☐	☐	☐
16. Exceeding the displayed speed limit by more than 30km/h	☐	☐	☐	☐	☐
17. Tailgating or following the vehicle in front too closely	☐	☐	☐	☐	☐
18. Failing to stop at a red light	☐	☐	☐	☐	☐
19. Turning where U-turns are prohibited	☐	☐	☐	☐	☐
20. Making a turn without indicating	☐	☐	☐	☐	☐

Accident Potential *[please tick the box you feel best describes the likelihood the behaviour may result in an accident]*	Highly Unlikely	Fairly Unlikely	Neutral	Fairly Likely	Highly Likely
21. Driving with a blood alcohol level 50% over the legal limit	☐	☐	☐	☐	☐
22. Driving with one or more badly worn tyres	☐	☐	☐	☐	☐
23. Passing another vehicle where visibility is obscured	☐	☐	☐	☐	☐
24. Failing to make a full stop at a stop sign	☐	☐	☐	☐	☐

Risk Taking Behaviours *[please tick the box that best describes the frequency with which you engage in the following behaviours]*	Never	Rarely	Sometimes	Often	Always
25. Drive recklessly because others expect me to do it	☐	☐	☐	☐	☐
26. Drive fast to show others I am tough enough	☐	☐	☐	☐	☐
27. Drive fast to show others I can handle the car	☐	☐	☐	☐	☐
28. Break traffic rules due to peer pressure	☐	☐	☐	☐	☐
29. Drive fast because the opposite sex enjoys it	☐	☐	☐	☐	☐
30. Exceed the speed limit in built up areas (more than 10km/h)	☐	☐	☐	☐	☐
31. Exceed the speed limit on country roads (more than 10km/h)	☐	☐	☐	☐	☐
32. Overtake the car in front of me when it is driving at the speed limit	☐	☐	☐	☐	☐
33. Drive too close to the car in front	☐	☐	☐	☐	☐
34. Bend the traffic rules in order to get ahead in traffic	☐	☐	☐	☐	☐
35. Ignore traffic rules in order to get ahead in traffic	☐	☐	☐	☐	☐
36. Drive on a yellow light when it is about to turn red	☐	☐	☐	☐	☐
37. Disregard red light on an empty road	☐	☐	☐	☐	☐
38. Drive the wrong way down a one-way street	☐	☐	☐	☐	☐

Driver Confidence *[How nervous do you usually feel?]*	Never	Rarely	Sometimes	Often	Always
39. When overtaking	☐	☐	☐	☐	☐
40. When turning right	☐	☐	☐	☐	☐
41. When negotiating a mini roundabout	☐	☐	☐	☐	☐
42. When negotiating a large roundabout	☐	☐	☐	☐	☐
43. When joining a motorway	☐	☐	☐	☐	☐
44. When changing lines on a motorway	☐	☐	☐	☐	☐
45. When driving in heavy traffic	☐	☐	☐	☐	☐

Driver Confidence *[When driving:...*	Not at all	A little	Somewhat	Very	Extremely
46. How relaxed do you usually feel?	☐	☐	☐	☐	☐
47. How stressed do you usually feel?	☐	☐	☐	☐	☐
48. How confident do you usually feel?	☐	☐	☐	☐	☐
49. When you are driving and you are suddenly faced with a potentially dangerous situation, how flustered do you become?	☐	☐	☐	☐	☐
50. When you are driving and things happen quickly giving you little time to think, how calm do you remain?	☐	☐	☐	☐	☐

Driver Strength *[how **difficult** would you find the following activities]*	Not at all	A little	somewhat	Very	Extremely
51. Opening a jar	☐	☐	☐	☐	☐
52. Lifting a 10kg bag of potatoes into a shopping trolley	☐	☐	☐	☐	☐
53. Lifting a couch up to vacuum underneath it	☐	☐	☐	☐	☐
54. Bringing a wheelbarrow of wood in for the fire	☐	☐	☐	☐	☐
55. Cutting a pumpkin in half	☐	☐	☐	☐	☐

Figure 5. Examples of three common steering wheel hand positions when driving.

Two Hands
•Two hands on the top half of the steering wheel

One hand
•One hand on the top half of the steering wheel

Zero hands
•Zero hands on the top half of the steering wheel

Hand Position Beliefs *[Please indicate to what extent you agree or disagree with the following statements]*	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
56. Placing two hands on the top half of the steering wheel would give me greatest control of the vehicle	☐	☐	☐	☐	☐
57. I would be putting myself at risk driving with zero hands on the top half of the steering wheel	☐	☐	☐	☐	☐
58. You need two hands on the wheel when slowing down in a hurry	☐	☐	☐	☐	☐
59. Driving with zero hands on the top half of the steering wheel would give me enough control of the vehicle to get out of any dangerous situation	☐	☐	☐	☐	☐
60. It does not matter where you place your hands on the steering wheel, you will always have the same level of control	☐	☐	☐	☐	☐

Figure 5 above shows examples of three common steering wheel hand positions. In your opinion, which of the three hand positions best shows:	**Two Hands**	**One Hand**	**Zero Hands**
61. Your typical hand positions when driving	☐	☐	☐
62. Your hand position on an 80km/h road	☐	☐	☐
63. The most natural hand positions when driving	☐	☐	☐
64. Your hand positions when relaxed	☐	☐	☐
65. Your hand positions when tense	☐	☐	☐

66. **How long did this survey take you to fill out?**	.... **mins**		
67. **How difficult was this survey?**	☐ Very easy	☐ About right	☐ Very hard

Comments (we welcome your comments regarding any aspect of this survey)

....
....
....
....
....
....
....

WE REALLY APPRECIATE THE TIME YOU TOOK TO FILL IN THIS SURVEY. PLEASE REMEMBER TO FILL IN THE PRIZE DRAW CARD TO GO INTO THE DRAW TO WIN $500 WORTH OF MTA VOUCHERS.

Appendix B Night-vision equipment options

Most technological night-vision devices use a combination of two approaches: enhanced spectral range, and enhanced intensity range.

- **Enhanced spectral range** techniques make the viewer sensitive to types of light that would be invisible to a human observer, such as near-infrared and ultraviolet radiation.
- **Enhanced intensity range** is simply the ability to see with very small quantities of light, such as through the use of an image intensifier, a gain multiplication CCD, or an array of very low-noise, high-sensitivity photodetectors.

B1 Infrared

The human eye is sensitive to wavelengths of light in the range 450–750 nanometres (nm). Wavelengths longer than 750nm are known as infrared, and are invisible to the human eye. Infrared cameras may operate with wavelengths as long as 14,000nm (14μm). By capturing information from outside the visible spectrum, and then reproducing it as visible light, the infrared camera is able to use light that is otherwise 'wasted' by the human eye, and hence imaging is possible even in conditions where little or no visible light is available.

B2 Far infrared/thermagraphic camera

All objects emit a certain amount of black-body radiation as a function of their temperature. Generally speaking, the higher an object's temperature, the more it emits infrared radiation as black-body radiation. A thermagraphic camera is sensitive to this infrared radiation, and produces images of the intensity of heat (over a certain infrared/temperature band) being received from the different regions of the field of view. These images usually use 'false' colour to denote received intensity, rather than saturation as in 'normal' photos. Because of the long wavelength of infrared light relative to visible light, the resolution of thermagraphic camera images is usually somewhat lower than that of visible-light cameras, and resolutions of 160x120 or 320x240 pixels are typical.

Infrared detectors (for cameras) come in two varieties – cooled, and uncooled. Infrared radiation is experienced as radiated heat, and the infrared detector experiences the radiation by its heating or cooling effect. If a detector is actively cooled (to approximately minus 200°C) then it can detect the radiation with a much greater sensitivity than if it is uncooled, and hence produce a much better image. However, the equipment needed for cooling is usually bulky and the manufacturing process for the detectors is expensive. Uncooled detectors sacrifice image quality for economy and portability, and rely on detectors that work at ambient temperature, or at a stabilised temperature very close to ambient.

Benefits:

- can work in zero-visible-light conditions (pitch black)
- suitable for imaging sources that produce heat, such as warm-blooded animals, etc.

Drawbacks:

- image is not necessarily representative of appearance under daylight conditions.

B3 Image intensifier

An image intensifier works by amplifying incoming visible or near-infrared light, so that the resulting image is of a higher intensity (contrast) than is visible with the naked eye. Modern systems use the photoelectric effect in two stages: the first produces a single electron for every incident photon from the source, and the second produces a cascade of electrons from the incident photoelectrons. These electrons then excite a phosphor screen to produce a strongly intensified image. Higher levels of amplification generally lead to greater image noise. Many systems use a green phosphor near the peak of human light sensitivity (555nm) to achieve the maximum signal-to-noise ratio possible from the measurement chain (which necessarily includes the human eye).

Night-vision goggles typically use this method to produce visible images in very low light conditions, as the technology is portable and consumes little power. There are four generations of night-vision technology, with generations 0 and 1 relying on vacuum tubes, and generations 2 and 3 utilising Microchannel Plate (MCP) technology for greatly enhanced image quality, amplification, portability, and power consumption.

Benefits:

- portable because of light weight and low power consumption
- work under a wide range of ambient light levels
- can benefit from active infrared illumination.

Drawbacks:

- only work when there is some light in the visible or near-infrared spectrum
- not sensitive to body heat.

B4 Active infrared imaging

Using an image intensifier as described above on ambient levels of light is called passive infrared imaging. Active infrared imaging involves illuminating the area to be observed with an infrared light source. The light source is invisible to the naked eye, but the reflections off surfaces are visible to the night-vision device. Sources at 850nm will have a dull red glow, and sources at 940nm are completely invisible to the naked eye.

B5 Depth perception

Night-vision equipment does not prevent normal depth perception – though it should be clear that the images received are not literally through the binoculars, but rather are a projected image on a tiny screen that is viewed by the individual wearing the equipment.

B6 Fog and rain

Night-vision equipment is very responsive to reflective ambient light; therefore, the light reflecting off fog or heavy rain causes much more light to go towards the night-vision unit and may degrade its performance.

B7 Night-vision equipment performance attributes

There are three important attributes for judging the performance of night-vision equipment: sensitivity, signal and resolution.

- Sensitivity, or photoresponse, is the image tube's ability to detect available light. It is usually measured in 'A/lm', or microamperes per lumen, and does not usually have standard IR illuminators. IR illuminators can sometimes be used in order to get acceptable performance under low-light conditions.
- Signal plays a key role in night-vision performance. An MCP is used to transfer a signal from input to output.
- Some equipment includes magnified optics to give the illusion that they have higher resolution, but in these, the field of view is sacrificed.

Table B1 Distance and magnification chart

Detection range by a person 6ft tall	Full moon .1 lux	Qtr. moon .01 lux	Starlight .001 lux	Overcast .0001 lux
Generation 3 night-vision equipment	890yds	850yds	601yds	220yds
Generation 2 night-vision equipment	690yds	650yds	430yds	160yds
Without night-vision equipment	250yds	50yds	*	*

* Not detectable