Impact on Driver Behaviour of Overtaking Lane Design for New Zealand Roads

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An Important Note for the Reader

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Contents

Contents: Chapter 4.2 *continued*

Contents: *continued*

Executive Summary

Introduction

The aim of this research, (conducted in 2003 on state highways in the upper North Island, New Zealand), was to improve safety at, and around, passing lanes by providing a better understanding of the impact of lane design on driver behaviour. As previous studies have shown, effective passing lane design increases driver safety both within the passing lane and beyond it.

This project was divided into four stages:

Stage 1 Review of available information about passing lanes (research, crashes, and lane design).

Stage 2 On-road measures of driver behaviour at passing lanes.

Stage 3 In-depth analysis of crashes related to overtaking when using the passing lane in the opposing direction.

Stage 4 Simulator-based study of passing lane merge design.

Stages 1 & 2

Stages 1 and 2 gathered information about issues related to passing lanes from a wide range of sources and provided a focus for further study.

Stage 1 consisted of a literature review, an analysis of crashes using the Land Transport Safety Authority CAS (Crash Analysis System) database, and consultation with industry experts.

Stage 2 consisted of field measurements using both video and traffic counting tube measures of driver behaviour at two passing lanes on SH29. Three main accident types were identified from the information gathering process:

- crashes related to overtaking in the opposing direction[1],
- crashes related to merge area design, and
- loss of control crashes.

As a result, the research team, in consultation with Steering Committee members, then decided to concentrate further efforts on studying two of these types of crashes, by conducting:

- a detailed analysis of opposing direction crashes;
- a simulator-based study examining alternative passing lane merge designs and their impact on driver behaviour.

These two studies comprised Stages 3 and 4.

Stage 3

To complete the detailed analysis of the opposing direction crashes, CAS database crash reports were examined in detail. In addition, a full environmental survey of 21 of the crash sites identified by CAS was completed, and Transit Regional engineers were contacted for their comments. A survey was then conducted of drivers to test their understanding of the rules relating to yellow lines and overtaking.

[1] This refers to accidents that occurred when traffic travelling in the opposing direction to that of vehicles in the passing lane crossed the centre-line into the passing lane to overtake vehicles. As long as the driver is not restricted by yellow 'no overtaking' lines, this is a legitimate manoeuvre. See Figure 4.1 in the report for further clarification.

The results of these analyses identified several issues that may contribute to these types of crashes:

1. Driver attitudes and behaviours, with younger males being more likely to be involved in this type of crash;
2. Driver frustration (identified by industry experts as a concern);
3. Longer vehicles seemed to be over-represented in crashes of this type, with 47.5% of crashes involving drivers attempting to overtake longer vehicles;

Several engineering design factors were also identified across the crash sites:

1. A number of sites lacked an "escape route" if errors in driver judgement had been made.
2. Sealed shoulders were rarely of a width that a driver could move out of the way to avoid a crash.
3. Sloping verges, ditches and banks appeared to contribute to the unforgiving nature of these sections of road.
4. Sight distances at some sites were found to be inadequate.
5. The current criteria for installation of double yellow no-overtaking lines may not adequately address the specific problems and factors that occur with overtaking manoeuvres on three-lane sections of road.

As a result of these findings several changes to overtaking lane design were suggested and listed below.

Stage 4

To examine the impact of passing lane merge design on driver behaviour, a simulator-based study of various merge designs was undertaken. Results suggested that geometric design (correctly placing the merge in relation to road geometry, and allowing for an appropriate taper length) is particularly important in promoting appropriate driver behaviour at merges.

Alternative treatments that were tested (such as early termination of the centreline that divides the passing lane, and paint treatments) either had a negative impact on driver behaviour or no impact at all. In addition, the negative reaction of drivers to the early termination of the passing lane centreline also indicated that they would not be comfortable with this treatment on the road. The conclusion was that these types of treatments could not substitute for good geometric design.

Suggestions for Improving Passing Lane Design

More detailed study into the implications of individual suggestions should be undertaken before considering implementation of the changes suggested here:

- Ensure all merge tapers are constructed to current standards, i.e. with Austroads standard taper lengths.
- Avoid blind merges if at all possible.
- Ensure all shoulders comply with the Transit NZ minimum width of 1.5 m. Widening to a minimum of 2 m is preferred to provide an 'escape route' for drivers involved in potential crashes.
- Increase passing lane opportunities to reduce driver frustration and the related increased risk taking.
- Consider widening the lane used for the opposing lane to provide overtaking opportunities for downhill traffic.

- Install wide double yellow lines with vibraline on high-risk sections of 3-lane or multi-lane roads.
- Where traffic volumes are high, consider installing a solid median barrier between the opposing lane and the passing lane.
- Install warning signage at potentially hazardous areas where some confusion is likely about actual available sight distances, and where there is some uncertainty in which lane vehicles are to travel.
- Increase education to the motoring public about safe overtaking.
- Install warning signs at locations where poor driving conditions caused by adverse weather, such as icy conditions, occur.
- Remove 'pseudo' passing lanes, i.e. hatched shoulders, or treat the merge of such areas in the same manner as for passing lane merges.

Abstract

This research, carried (conducted in 2003 on state highways in the upper North Island, New Zealand), aimed to improve safety at passing lanes by examining the influence of lane design on driver behaviour. It was carried out in 4 stages:

- Stages 1 and 2 were a review of information about driver behaviour at passing lanes, and on-road measurements of overtaking behaviour.
- Stage 3 was a detailed analysis of crashes related to overtaking when using the passing lane in the opposing direction, and to analyse factors common to these crashes.
- Stage 4 was an analysis of the impact of alternative merge area designs on driver behaviour using a driving simulator.

Suggested changes to road design to alleviate these issues are provided.

1. Introduction

1.1 Background

In the year 2001, approximately 5.8% of fatal crashes and 3.3% of injury crashes on New Zealand roads occurred during overtaking manoeuvres (LTSA 2001). While the number of injury level crashes related to overtaking has fallen slightly in the last five years (1996-2001), the number of fatalities has remained steady. Research has shown that the provision of well-designed passing lanes can have a significant effect in reducing the number of overtaking-related crashes by providing drivers with the opportunity to pass safely. However, care must be taken to design passing lanes in a manner that encourages safe driving behaviour, and provides the greatest efficiency in terms of number of vehicles passed. While some research has been conducted on passing lane design, few conclusions have been reached to date regarding optimal lane design. Continuing to examine issues related to the impact of passing lane design on driver behaviour is of interest.

Previous research provided some insights into the possible impacts of passing lane design. May (1991) showed that subtle changes in lane design could affect the number of drivers who move into the main lane and as a result, affect an increase in the number of vehicles passed. (Previous work conducted by TERNZ (Charlton et al. 2001) has supported such findings, verifying the safety and efficiency of the diverge treatments introduced onto New Zealand roads after July 2000.) These studies confirm the importance of correct design of passing lanes. However, Mutabazi et al. (1998) raised further questions about the design of passing lanes. In this US study, drivers identified problems at passing lanes that were associated with their failure to follow signs and markings correctly, indicating that improvements in lane marking and signage may still be required to optimise driver behaviour.

The aim of this research (conducted in 2003 on state highways in the upper North Island, New Zealand), was to improve safety at, and around, passing lanes by providing a better understanding of the impact of lane design on driver behaviour. As the previous studies showed, effective passing lane design will increase driver safety both within the passing lane and beyond it.

1.2 Technical Approach

This project was divided into four stages, as outlined in Sections 1.2.1 – 1.2.4:

- Stage 1 Review of available information about passing lanes (research, crashes, and lane design).
- Stage 2 On-road measures of driver behaviour at passing lanes.
- Stage 3 In-depth analysis of crashes related to overtaking in the opposing direction.
- Stage 4 Simulator-based study of passing lane merge design.

Stages 1 and 2 gathered information about driver behaviour that would assist the research team in deciding on which aspects of passing lane design to focus for the rest of the study.

1.2.1 Stage 1 – Review of available information about passing lanes

Stage 1 consisted of an analysis of issues related to passing lanes, with information being drawn from a broad variety of sources in the following three steps:

1. A full literature review of studies relating to passing lanes both in New Zealand and overseas was undertaken.
2. An analysis of crashes at passing lanes was completed. The CAS (Crash Analysis System) database, compiled by the LTSA (Land Transport Safety Authority), was used to identify crashes that had occurred within or near passing lanes. The nature and cause of the accident was then identified.
3. Industry experts, who were primarily regional engineers, were consulted regarding any issues they had experienced with passing lane design, (although most of these experts were from within New Zealand, overseas experts were also contacted).

1.2.2 Stage 2 – On-road measures of driver behaviour at passing lanes

Stage 2 consisted of field measurements of driver behaviour at the passing lanes. These on-road measurements were taken by an independent company (Traffic Planning Consultants Ltd). The lanes from which measurements were taken were those used during a previous TERNZ study of passing lanes (Charlton et al. 2001). The on-site measurements included automated site-speed measurements at set locations, and field data collection of actual patterns of merging behaviour. A review of the data gathered is available in Chapter 3. In addition, the on-road measurements gathered by Traffic Planning Consultants were compared to simulator-based passing lane data collected previously by TERNZ. These comparisons were presented in a supplementary report (Brown & Vroegop 2002; pp.115-138 of this report).

From knowledge gained in Stages 1 and 2 of this study, the research team, in consultation with steering group members, decided to concentrate further efforts in two areas:

1. A detailed analysis of opposing direction crashes.
2. A simulator-based study examining alternative passing lane merge designs and their impact on driver behaviour.

These two areas of study comprised Stages 3 and 4 of this research.

1.2.3 Stage 3 – Analysis of crashes related to overtaking in the opposing direction

To gather in-depth information about opposing direction crashes, a detailed analysis of these crashes was conducted.

1. The CAS database was used to identify crashes of this type and to examine the details of the crash report.
2. A road environmental survey of 21 sites where crashes of this type had occurred was conducted.
3. Regional engineers were contacted to gather their views about crashes of this type.
4. A survey was conducted to test driver understanding of the road rules related to yellow lines.

On the basis of these data, conclusions and suggested changes to overtaking lane design are outlined in Chapter 4 of this report.

1.2.4 Stage 4 – Simulator-based study of passing lane merge design

To further examine alternative designs for passing lane merges and their impacts on driver behaviour, a simulator-based study was conducted. Simulated roads were developed that presented drivers with a variety of merge designs including various alternative paintwork and geometric designs. Driver performance data, including vehicle speeds, accelerator and brake position, lane position, and following distance, were collected throughout the simulation and the results were analysed to determine the effect that the alternative treatments had on driver behaviour. The results of this phase of the study are presented in Chapter 5.

2. Review of Available Information about Passing Lanes

Stage 1 of the study consisted of gathering information about passing lanes from as many different sources as possible. Information was gathered through literature reviews, crash data analysis, and consultation with industry experts. This information was then combined with the knowledge gained through on-road measurements of driver behaviour (Chapter 3 of this report) to identify key areas for further study.

2.1 Review of Literature Examining Driver Behaviour in Passing Lanes

An analysis of the available literature on passing lanes, both in New Zealand and internationally, showed that few major advances have been made in passing lane research since the review completed by Charlton et al. (2001). While there has been research into the length, spacing, and basic road geometry of passing lanes, most of it was based on a variety of quantitative models and simulations or willingness-to-pay considerations. However, the current literature review did identify a few points of interest regarding passing lanes.

Perhaps one of the most important research findings in this area highlights the deficits in driver judgments when making decisions about whether to overtake. Lerner et al. (2000) stated that research from both laboratory simulations and instrumented vehicles indicated that about one-third of drivers overestimate the time they have in which to make a passing manoeuvre, and underestimate the time required to pass a vehicle, especially when that vehicle is a truck. When time-available and time-required judgements were combined, 58% of drivers' estimates were safety-negative errors for passing a truck, and 26% for passing a car. These results highlight the importance of effective passing lane design to assist drivers to make safe passing decisions and to limit the need for overtaking on two-lane stretches of road.

Other research has more specifically addressed paintwork, signage, and geometric design issues at passing lanes. Mutabazi et al. (1998) conducted a survey of drivers in the US and, through this, identified problems associated with failure to follow signs and markings properly, and failure to use lanes. This research suggests some deficits in the design of signage and markings that could gainfully be addressed. The suggestion that more effective passing lane design can be effective in improving driver behaviour and the number of vehicles passed is supported by May (1991). May's study found that passing lane entrance designs (with continuity lines through the diverge section) can increase the number of vehicles that enter the basic lane and the number of passes per passing-lane length. May also found that passing lanes from 0.25 to 0.75 miles (0.4 to 1.2 km) long appeared to be the most effective, depending on downstream roadway and traffic conditions. A recent laboratory simulation of this design verified May's findings regarding the effectiveness of diverge continuity lines for New Zealand drivers and roads (Charlton et al. 2001), and continuity lines have become the standard treatment for New Zealand passing lanes since July 2000.

While May (1991) addressed some issues related to passing lane diverge design, the design of the merge portion of passing lanes continues to be a problem. A variety of design approaches that have been considered and tested include:

- A merge continuity line giving precedence to the overtaking vehicles (Australia);
- Arrows and flush medians painted in the passing lane giving precedence to traffic in the outside lane (Germany); and
- A cessation of lane lines at the start of the merge taper with hatched run-out painted on the road shoulder at the end of the merge area, tapering back to the standard shoulder width (New Zealand).

However, no systematic data have been collected to show how these treatments affect driver behaviour.

One study that has addressed some of these issues is by Charlton et al. (2001). This research showed that the presence of a merge continuity line (as in the Australian treatment) had the effect of slowing drivers' speeds, reducing headway distances in the merge taper, and reducing overall overtaking rates. In comparison, the hatched run-out treatment (as for the New Zealand treatment) had the effect of delaying a driver's move to the right lane in the merge section. Geometry also appeared to impact on driver behaviour and there was some indication that, in challenging situations (shorter sight distances and more taxing road geometry), drivers rely more heavily on road markings and signage. The results of Charlton et al. concurred with overseas studies that have shown that a merge taper of approximately 200 m length is required for high-volume two-lane highways (Frost & Morrall 1998).

Several issues are highlighted by this literature review, and in particular the importance of providing drivers with safe and efficient passing opportunities is emphasised. In addition, clearly some issues remain to be resolved with the design of passing lane merges. While several options have been trialled, no definitive evidence has been gained to date about their impact on driver behaviour.

2.2 Crash Data Analysis

To gather information about the number and nature of passing lane crashes, the CAS database (collated and managed by the LTSA) was utilised.

While the database contains a searchable category for overtaking crashes, it does not distinguish between those occurring at passing lanes and those occurring on two-lane stretches of road. Therefore, the 4000 crash reports for overtaking crashes that have occurred in the North Island between 1996 and 2001 were examined manually. The crash reports are scanned copies of the crash report filled out by the attending officer at the scene of the accident.

Because of the nature of the reports (some reports have scanned illegibly, others do not have enough information to understand the details of the crash, and a few are missing) and because only North Island crashes were surveyed, the following figures represent only a sample of the crashes that have occurred at passing lanes on New Zealand roads.

For the sample of crashes derived from the crash reports, between 1996 and 2001, 292 crashes were identified as caused by overtaking at passing lanes (an average of 48.67 crashes per year). Twelve crashes included at least one fatality (an average of 2 per year) and 115 crashes included at least one injury (an average of 19.17 per year).

2.2.1 Causes of Crashes in Passing Lanes

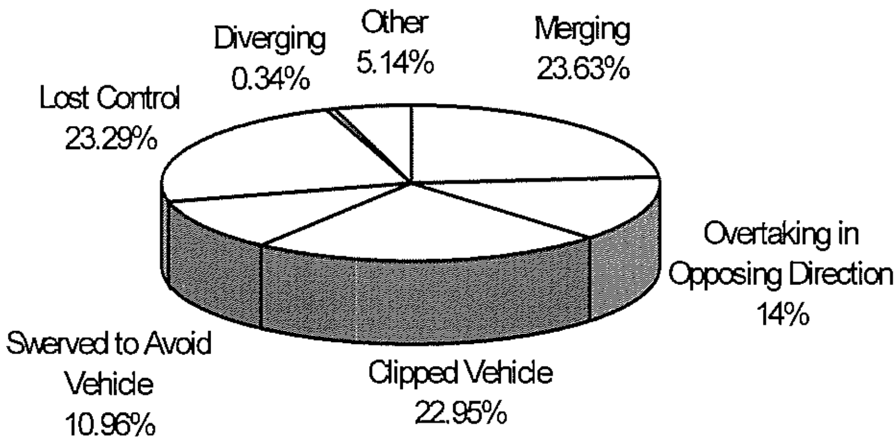

Figure 2.1 Causes of crashes in passing lanes for the period 1996-2001.

The causes of the crashes identified in this analysis were determined from the crash reports recorded in the CAS system. As Figure 2.1 shows, several prominent factors contributed to the passing lane crashes. The leading factors were: one car clipping another when changing lanes (23%), failing to merge correctly (24%), losing control within passing lane (23%), and overtaking using a passing lane for the opposing direction (14%).

2.2.2 Injury Rates for Overtaking Crashes in Passing Lanes

Table 2.1 provides details about the passing lane crashes within each of the main crash categories (as in Figure 2.1). Several key points emerge from an examination of the table. First, the injury statistics clearly show that the category 'overtaking in the opposing direction' contains a high proportion of fatalities. In fact 15% of crashes in that category resulted in at least one fatality, compared to less than 5% in all other categories. In addition, a high number of crashes in this category also resulted in serious injuries.

An examination of the part of the day (i.e. day v night) and road conditions (wet v dry) at the time of these crashes indicates that only 38% of the loss of control crashes occurred under dry road conditions. In contrast 75% of all the other crashes that resulted in injuries or fatalities occurred during dry road conditions.

Table 2.1 Summary of CAS crash data for the period 1996-2001.

Category	No.	Fatal	Serious Injury	Minor Injury	Time % During Day	Road Condition % Dry
Failing to merge	69	1	7	17	80	77
Loss of control	68	2	9	28	78	38
Clipped other vehicle changing lanes	67	2	6	14	73	81
Overtaking in the opposing direction	40	6	8	16	70	63
Swerving to avoid another vehicle	32	0	3	6	81	66
Diverging	1	1	0	1	100	100

2.2.3 Further Research on Crashes in Passing Lanes

These results suggest several areas that may benefit from further research:

- Because overtaking in the opposing direction more often results in serious injuries or fatalities, the conditions under which drivers undertake these manoeuvres need to be understood.
- A substantial proportion of crashes appear to occur because drivers fail to merge correctly, and this cause may be addressed by re-designing the merge area.
- The other crash category that is prominent (both in terms of its frequency and the likelihood of the crash resulting in an injury or fatality) is loss of control.

2.3 Industry Consultation

In addition to information gathered through literature reviews and crash analyses, roading and transport authorities (both in New Zealand and overseas) were questioned about what they perceived to be the most important concerns relating to passing lane design. As a result, several issues were identified as needing further study:

- Optimising the frequency of passing lanes

  Several engineers expressed concern about the frequency and capacity of passing lanes on New Zealand roads.

- The appropriate placement of passing lanes within existing road geometry, and how to reconcile the need for regular overtaking opportunities

  Several engineers felt strongly about the placement of passing lanes in relation to curves and side roads. Some were interested in how to optimise the placement of lanes to encourage appropriate driver behaviour.

- The use of double solid yellow no-overtaking lines at all passing lanes to prevent motorists overtaking in the opposing direction

  Several engineers were interested in the possibility of providing continuous double yellow lines at passing lanes. Views were mixed about how this intervention would affect driver behaviour.

There was also some interest in whether drivers understood the road rules relating to yellow lines. Overseas engineers considered the best design practice was to include double barrier (double yellow lines) at all merge and diverge areas, and to restrict overtaking from the opposing lane to low volume roads of less than 4,000 vehicles per day, and only where acceptable sight distances were available, with no intersections.

- The placement and design of merge areas

  Several engineers commented on the signage at merge areas, and others commented about the placement of merges in the road geometry. While they were clearly concerned about merge design, few had considered potential paintwork treatments to improve merging behaviour.

- The appropriateness of establishing which lane has priority at the merge area

  Several overseas researchers supported the clear establishment of priority at the merge area. However, in general, engineers in New Zealand consider that the establishment of priority would not work in the New Zealand context.

- The efficacy of the hatched shoulder run-out in the merge area (currently employed in the New Zealand standard)

  Engineers in New Zealand report mixed experiences with the hatched shoulder run-out at the merge area. Although one commented that it worked well and was well received, several others commented that they had had negative experiences with it. Therefore, like other aspects of merge area design, currently consensus about this issue is not apparent.

- Shoulder widths

  Overseas opinion is that shoulder widths on passing lanes should be consistent with the widths provided on the two-lane road, before and after the passing lane.

2.4 Conclusions from Stage 1 Review

The information gathered during the literature review, crash data analysis, and expert consultation indicated several areas where further research may be necessary. In particular, further research into the design and placement of merges was suggested by the available literature, crash data, and consultations with regional engineers.

In addition, because of the increased risk of serious or fatal injury with crashes related to vehicles overtaking in the opposing direction (compared to other types of crashes in the vicinity of passing lanes), further research into these types of crashes seemed necessary.

Research about overtaking in the opposing direction was also of interest because of the debate surrounding the frequency with which yellow lines should be used to prevent overtaking in the opposing direction in passing lanes.

Loss of control crashes also warranted some consideration due to the sheer number of crashes in this category.

3. On-Road Measures of Driver Behaviour

In addition to the background information gathered in Stage 1 of this study, on-road measures of driver behaviour were gathered for Stage 2 to provide the research team with information about typical behaviour at passing lanes. These measures were also intended to identify any areas where non-optimal driver behaviour occurred. On-road measurements consisted of traffic flow measures using traffic counting tubes, and video recordings of driver behaviour at merge areas. The traffic counting tubes provided information about traffic volumes, driver speeds, lane selection, and headway duration.

3.1 Traffic Counting Tube Measurement of Driver Behaviour

3.1.1 Measurement Locations

Traffic counting tube measurements were collected at two sites with different geometry on SH29, across the Kaimai Range, between Waikato and Bay of Plenty, North Island. The first site chosen was a 1-km long passing lane commencing east of the Kaukumoutiti (Boulder) Stream bridge. This passing lane was on a straight stretch of road (including the merge area) and will henceforth be referred to as the 'straight merge site'. The second site chosen was a 2-km long passing lane located close to the summit of the Kaimai Ranges, terminating a short distance east of Kaimai Primary School. This site was located on an uphill stretch and the merge area was obscured by a curve in the road (henceforth referred to as the 'blind merge site'). A distance of approximately 1 kilometre separated the two stretches of passing lanes.

To collect the traffic flow data, five traffic tube counters had to be installed at each site (Figure 3.1). The data collected at measurement locations 1 and 5 of each site (henceforth called 'locations') was from a single lane of traffic. At locations 2, 3, and 4 the counters were configured to record the traffic characteristics of each lane. Location 3 was placed at 250 m before the merge area.

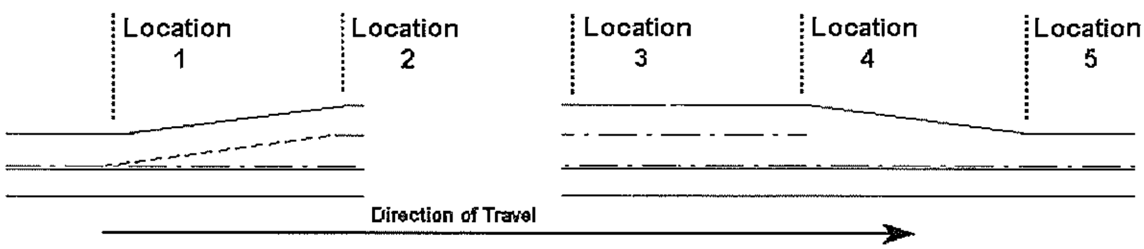

Figure 3.1 Measnrement locations 1-5 nsed for the collection of traffic flow data on both passing lanes (straight and blind).

The data collection ran for 24 hours from midnight of each day. In an effort to capture traffic patterns that were typical of 'normal' weekday behaviour, the collection of the field data was timed to avoid school holidays and short weeks where the traffic flows may be affected by public holidays, times when road works were planned in the area, and particularly bad weather conditions.

3.1.2 Speed Profile

The measurements taken with the tube counters were collated and traffic speed profiles (average speeds for traffic across both lanes) were generated for each passing lane (Figure 3.2).

As Figure 3.2 shows, traffic in the blind diverge (locations 1 and 2) exhibited very consistent mean speeds (98.0 kph and 98.6 kph respectively) across the two locations. By comparison, a distinct increase in mean speeds for traffic occurred in the straight diverge for locations 1 and 2 (92.2 kph, 97.1 kph respectively).

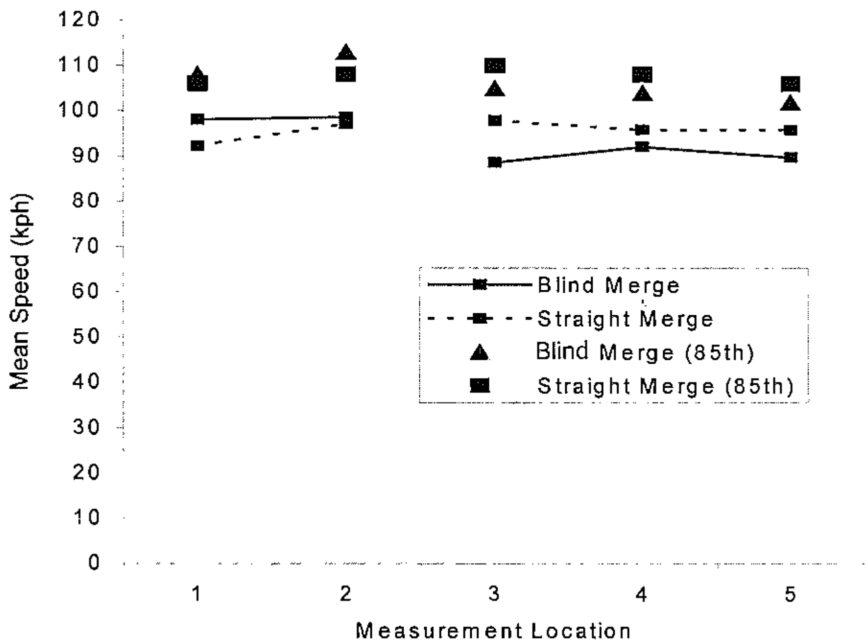

Figure 3.2 Vehicle speeds for the two on-road sites[2] at the diverge (on left) and merge (right) sections.

Mean speeds at the merge area differed notably between passing lanes. Recorded speeds were noticeably slower for vehicles at the blind merge site (ranging from 88.6 kph to 92.11 kph). By comparison, vehicles at the straight merge site showed higher speeds (ranging from 97.9 kph to 95.8 kph). Much of this difference may be attributed to the geometry of the sites in which the two merges occurred. At the blind merge site, drivers were cresting a rise as they approached the merge area, after an extended climb. The speed profile for this merge shows drivers increasing their speeds slightly from locations 3 to 4, and then decelerating from locations 4 to 5. The

[2] Average speeds combined both the left and right hand lanes in the overtaking direction.

profile for the straight merge site shows a general decrease in speeds from locations 3 through to 5.

3.1.3 Lane Selection

Table 3.1 shows the percentage of vehicles that selected the left and right lanes at each of the five locations for each passing lane. Note that locations 1 and 5 only had one lane, so are essentially irrelevant. It shows that an overwhelming majority of vehicles selected the left lane, as one would expect.

Table 3.1 Vehicle lane selection for both on-road sites.

Blind Merge	Location 1	Location 2	Location 3	Location 4	Location 5
Left Lane (%)	100.00	87.94	71.91	89.93	100.00
Right Lane (%)	–	12.06	28.09	10.07	–
Straight Merge	Location 1	Location 2	Location 3	Location 4	Location 5
Left Lane (%)	100.00	91.87	90.68	91.14	100.00
Right Lane (%)	–	8.13	9.32	8.86	–

For both passing lanes, approximately 90% of vehicles remained in the left lane at all locations (apart from location 3 for the blind merge), though generally more drivers selected the left lane at the straight merge site than the blind merge site. The only notable exception to this is location 3 at the blind merge site. At this point approximately 30% of vehicles were in the right lane, which would seem to indicate that more vehicles overtook in this passing lane, and may be related to the hill slowing down heavier traffic.

3.1.4 Summary of Traffic Counting Tube Measurements

The results of the measurements provide some interesting information about driver behaviour at passing lanes. At both lanes there were several differences in driver behaviour. Although drivers travelled slightly faster throughout the passing lane with the straight merge, their behaviour was more consistent. They made fewer lane changes and maintained a more constant speed. When drivers travelled through the blind merge their behaviour was more varied with greater changes in speed and more lane changes.

3.2 Video Analysis of Driver Behaviour at Merge Areas

3.2.1 Methodology

TERNZ Ltd and Traffic Planning Consultants researchers undertook a video analysis of merging behaviour at the two geometrically different passing lanes described above.

Video was taken of the merge area from the beginning of the merge taper to beyond the end of the merge. It was undertaken on 5/9/02 (straight merge site) and 10/9/02 (blind merge site). The sites were recorded from 10:00–12:00 and 14:00–16:00 hours on each day, resulting in four hours of tape for each site.

The video was then examined to ascertain the number of instances at each site where two or more cars were still overlapped within the merge taper. Instances of inappropriate merging behaviour were placed in one of three categories:

- completing an overtaking manoeuvre that was started before the merge;
- beginning an overtaking manoeuvre within the merge but pulling back; and
- completing a whole overtaking manoeuvre within the merge.

3.2.2 Results

In total, 151 instances occurred where vehicles approached the merge area in a platooned formation and therefore had the opportunity to interact with other vehicles. In 34 (22.5%) of these instances at least one driver in the group failed to merge appropriately (18 at the straight merge site and 16 at the blind merge site). Of the 34 instances, 12 completed an overtaking manoeuvre that was started before the merge, 11 began an overtaking manoeuvre within the merge but pulled back, and 11 completed the whole manoeuvre within the merge. Road geometry did not appear to have a significant effect on driver behaviour.

However while the sample size at each merge is small (18 and 16 instances of poor merging), these results would appear to indicate that a notable proportion of drivers fail to merge appropriately. This type of behaviour is particularly risky in situations where vehicles are platooned and therefore interacting closely with each other.

3.3 Summary of Stages 1 and 2

The three main issues that emerged from these stages were:

- overtaking in the opposing direction,
- merge area design, and
- loss of control crashes.

The first two issues were further explored in this study because they were consistently identified as issues of concern with regard to passing lanes, as summarised in Sections 3.3.1 and 3.3.2.

3.3.1 Overtaking in the Opposing Direction

- Overtaking in the opposing direction was identified as the behaviour most likely to result in a fatality around passing lanes (CAS analysis);
- Drivers frequently underestimate the time they have available to complete an overtaking manoeuvre (literature review);

- Views were divided about the usefulness of providing double solid yellow lines for the whole length of the passing lane to prevent overtaking in lanes used by opposing traffic (industry consultation).

3.3.2 Merge Area Design

- The on-road analysis of cars approaching the merge in a platoon showed that in 22.5% of cases at least one car failed to merge correctly (from video analysis);
- A notable number of crashes were related to failure to merge (from CAS analysis);
- No clear agreement was found about how to design the merge area in terms of priority, signage, or marking (from literature review);
- Insufficient information is available on the placement of merges within existing road geometry, designation of priority, and design of the merge treatment (e.g. hatched run-outs) (from industry consultation).

These two issues are addressed in:
Chapter 4, Analysis of crashes related to overtaking in the opposing direction, and
Chapter 5, Passing lane merge design.

4. Analysis of Crashes Related to Overtaking in the Opposing Direction

As a result of the information gathered in Stages 1 and 2 of this study (reported in Chapters 2 and 3), it was decided to undertake an in-depth analysis of crashes that occurred as a result of drivers using a passing lane to overtake in while travelling in the opposing direction. This comprised Stage 3 of the study.

In this report, the term "passing lane" includes the diverge area, the two passing lanes, and the merge area (and the driver on that side of the road has a right-of-way to use it for passing). The term "opposing lane" refers to the lane on the opposite side of the road where traffic travels in the opposing direction (to that in the passing lane, and in which the driver on that side of the road does not have the right-of-way when using it for passing).

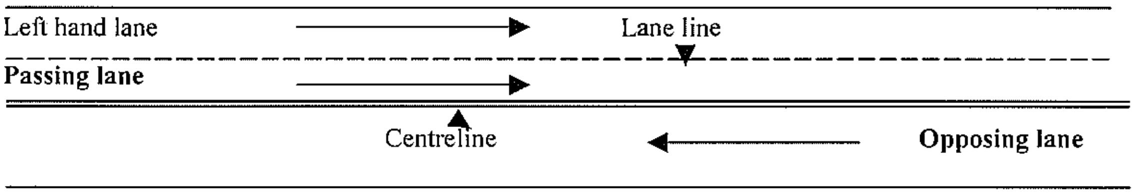

Figure 4.1 Configuration of a road showing passing and opposing lanes.

For Stage 3 of the study, four steps were undertaken:

1. A more detailed analysis using CAS database crash reports relating to these kinds of crashes (Section 4.1);
2. Environmental surveys were undertaken at 21 of the crash sites identified by the CAS reports (Section 4.2) so that a full analysis of the external conditions of the roads could be made;
3. Consultation with Transit Regional engineers for their comments (Section 4.3);
4. A survey of drivers to establish the degree to which they understood the road rules relating to yellow lines and overtaking (Section 4.4).

For each step the methods and results are described, with a detailed summary of the findings.

Conclusions drawn from the summaries are listed in Section 4.5. These are also the issues on which the suggested changes to passing lane design are based, as summarised in Section 4.6.

4.1 Detailed Analysis of CAS Crash Reports

4.1.1 Methodology

CAS database crash reports relating to crashes where drivers had overtaken in the opposing direction were analysed to gain a better understanding of the nature of these crashes and to provide a focus for the environmental surveys. The crash reports record several accounts of a crash including: those of the drivers involved in the crash, any witnesses, and the attending police officer, and a diagram of the crash scene. In the case of any disagreement between these parties regarding the causes of the crash, the view of the attending officer was taken as the definitive statement.

A total of 40 crash reports were analysed to find commonalities (i.e. common contributing factors) and patterns within the crashes (Appendix A). The issues examined in detail were: the age and gender of the driver who caused the crash, the vehicle movements that caused the crash, the types of vehicles involved in the crash, and the weather and road conditions at the time of the crash. Information about road geometry was also recorded.

4.1.2 Results

4.1.2.1 Driver Demographics

The demographic information (date of birth, gender) of the driver who was overtaking in the opposing direction to the passing lanes was recorded and analysed where it was available in the CAS database (Table 4.1). An analysis of this information revealed that most drivers were male (65%). Males are not over-represented in these types of crashes given the percentage of kilometres driven by males in a year (63%) (Charlton et al. 2002) and the percentage of male drivers involved in crashes in general (64.45%) (LTSA 2002).

In 9 of the 40 crashes (22.5%), the driver who was overtaking in the opposing direction left the scene before their details could be recorded. Therefore the crash could not be included in this analysis, and their gender and age are not known. Thus only those crashes for which the demographic information of the drivers had been recorded are presented in Table 4.1.

In terms of age, most drivers who were involved in crashes where they were overtaking in the opposing direction were aged 25 to 45 years (61.3%), which is an over-representation of these drivers given their involvement in all injury and fatality crashes. (Drivers (males and female) aged from 25 to 45 years accounted for 39% of all fatal and injury crashes in 2002 (LTSA 2002).)

The largest gender group involved in these crashes were males aged 25 to 45 years who accounted for 35.5% of the total group, again an over-representation (as male drivers aged from 25 to 45 years account for 27% of all fatal and injury crashes (LTSA 2002)).

Table 4.1 Gender and age distribution of drivers involved in crashes when overtaking in the opposing direction.

Age (years)	Male		Female	
	(n)	(%)	(n)	(%)
< 25	5	16.1	1	3.2
25 – 45	11	35.5	8	25.8
46 – 65	3	9.7	0	0
> 65	1	3.2	2	6.5

n = *number of population: total = 31.*
Of the original 40 reports, 9 could not be used as driver had left the scene of the accident.

4.1.2.2 Vehicle Movements Related to Crash

The vehicle movements related to the crash were analysed using the notes of the attending police officer. Analyses revealed three key themes for the movements of the vehicle that attempted to use the passing lane to overtake in the opposing direction. They were:

- drivers hitting opposing traffic head on,
- drivers hitting the vehicle they were overtaking and/or causing it to crash trying to avoid them, and
- drivers losing control trying to avoid oncoming traffic.

Table 4.2 provides a breakdown of the frequency of these movements.

Table 4.2 Classifications of the 40 vehicle movements in crashes related to vehicles overtaking in the opposing direction.

Movement Description	Frequency	%
Driver pulled out to overtake in the opposing direction and hit traffic in the opposing lane	14	35
Driver pulled out to overtake in the opposing direction and proceeded to merge back into his or her own lane too early, either clipping the vehicle being passed or causing it to crash	12	30
Driver pulled out to overtake in the opposing direction, swerved to avoid oncoming traffic, lost control or caused oncoming traffic to lose control	10	25
Other	4	10

4.1.2.3 Types of Vehicles Involved In Crash

CAS reports were also analysed to determine the number of crashes which involved heavy vehicles or longer than normal vehicles (e.g. cars towing trailers). The results of this analysis showed that, in 35% of crashes, the driver using the passing lane to overtake in the opposing direction was attempting to overtake a truck. In 5% of the crashes the driver was attempting to overtake another type of heavy vehicle (e.g. grader, bus), and in 7.5% of crashes the driver was attempting to overtake a car towing a trailer or boat.

In total, vehicles that are longer than average were involved in 47.5% of crashes of this type. Given the national average percentage of longer vehicles on the road, these results seem to indicate that longer vehicles are over-represented in terms of their involvement in this type of crash.

4.1.2.4 Weather, Road and Light Conditions at Time of Crash

To fully understand the circumstances of the crashes, several details were recorded regarding the conditions of the road at the time of the crash. These were the weather, wet or dry road surface, etc., and light levels at the time of the crash.

Table 4.3 outlines these weather conditions at the time of the crashes. It shows that most crashes (78%) occurred during favourable weather, which reflects the high percentage of crashes that generally occur during favourable weather (75% of all fatal and injury crashes, LTSA 2002). Only one crash occurred during heavy rain, which indicates that poor weather was probably not a contributing factor to most of these crashes.

Table 4.3 Weather conditions at time that analysed crashes occurred.

Weather Condition	Frequency	%
Fine	31	78
Light Rain	8	20
Heavy Rain	1	2

An outline of reported road conditions at the time of the crashes is presented in Table 4.4. As the table shows, the majority of crashes occurred on dry roads (65%). However, a notable proportion (30%) did occur on wet roads.

Table 4.4 Road surface conditions at time that analysed crashes occurred.

Road Surface Condition	Frequency	%
Dry	26	65
Wet	12	30
Icy	2	5

An examination of reported light levels was also conducted (Table 4.5). Crashes occurred during a range of light conditions, with 2/3 of the crashes occurring during the day in either bright or overcast conditions. These percentages reflect the general trends seen in general injury and fatal crashes related to road conditions (LTSA 2002).

Table 4.5 Light levels at time that analysed crashes occurred.

Light Levels	Frequency	%
Bright	13	33
Dark	12	30
Overcast	13	33
Twilight	2	5

4.1.3 Key Themes

Several key themes emerged from the in-depth analysis of CAS reports related to crashes where drivers used a passing lane to overtake in the opposing direction. Key findings were:

- While drivers from all demographic groups were involved in these crashes, male drivers aged 25-45 years were the most frequently involved group of drivers. This age group was, in general, over-represented in this type of crash in comparison to their involvement in injury and fatality crashes overall.
- The description of crashes in the CAS database showed three generic categories of vehicle movement related to the crashes.
- The records indicated that approximately half the vehicles being overtaken were heavy vehicles, including trucks, or vehicles towing trailers or boats.
- The crashes most frequently occurred in fine, dry weather, during the day, which indicates that they were not related to wet roads or poor visibility at night.

This analysis was not able to determine any commonalities in road geometry between crashes where drivers used a passing lane to overtake in the opposing direction. It was therefore decided that, to obtain greater detail of the physical road situation and the surrounding environs of the crash sites, environmental surveys at the sites identified in the CAS analysis would be undertaken.

4.2 Analysis of Environmental Surveys of Crash Sites

Surveys of the crash sites were undertaken to help establish the overall environment (or external conditions) where the crash took place. The CAS crash reports provided information on the weather and road surface conditions at the time of the crash, and basic information on the topography and road alignment. The environmental surveys provided additional information to expand the knowledge of conditions at the site.

Survey information included traffic volume and speed measurements, lane and shoulder widths, side features such as steep banks or cliffs, presence of obstructions at the road side, available sight distances, and road gradient and curvature. Appendices B–H list the sites surveyed and the external conditions measured.

4.2.1 Methodology

4.2.1.1 Aim

The aim of the environmental survey was to create a record of observations and measurements that would allow comparisons between the external conditions of roads where crashes had occurred because drivers used a passing lane to overtake in the opposing direction.

The survey form developed for this research project was based on one used for the Auckland Car Crash Injury Study (ACCIS), a research project undertaken by the Injury Prevention Research Centre at the University of Auckland. Geometric, topographic, and other physical features were recorded during visits to each site.

4.2.1.2 Data Collection

At each site two members of the research team recorded the physical features of the road for the environmental survey and took measurements of speeds of vehicles passing at that time.[3] From the vehicle speed measurements at the crash sites, average closing speeds were calculated (Section 4.2.2.7). Traffic volumes, including % heavy vehicles, for each site were obtained from Transit NZ (Section 4.2.2.8).

The external conditions recorded in the environmental survey included:

- Road geometry
- Carriageway / Lane widths
- Shoulder and verge widths, roadside features
- Sight distances
- Paintwork / Lane markings
- Vehicle speeds
- Vehicle closing speeds
- Traffic volumes

Before completing the environmental analysis of external conditions, an examination of the road geometry information available in the CAS database was conducted. The crash reports in the CAS database provide information about whether the road was hilly or flat, and whether the crash occurred on a corner or a straight piece of road. This enabled the researchers to develop some initial ideas about the nature of the sites.

Photographs were taken at each site from the same relative position to assist in identifying road geometry and layout.

4.2.2 Results

4.2.2.1 Road Geometry

Because they impact on sight lines, road gradient and curvature are two of the main geometric features that indicate whether a particular stretch of road is safe to overtake on.

Table 4.6 lists the CAS database information that was available relating to road geometry, and shows that most crashes occurred on hill roads (74.4%) in an area where the road was either straight (57.5%) or an easy curve (30%).

In comparison, the road gradient measured at crash sites showed that 62% of the sites surveyed were hilly (gradient of 5-15%; Appendix F) which is somewhat less than the CAS analysis of 74.4% on hill roads.

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3 The environmental surveys were completed at the crash sites indicated by the CAS database crash reports. However, the crash site may be some distance from the site where the driver made the decision to overtake, and began the overtaking manoeuvre.

Table 4.6 CAS information about road gradient and curvature for surveyed sites.

Road Gradient	Frequency	%
Hill Road	29	74.4
Flat Road	10	25.6
Horizontal Road Curvature		
Straight	23	57.5
Easy Curve	12	30
Moderate Curve	4	10
Severe Curve	1	2.5

However, the CAS analysis can be assumed to refer to the general area, whereas the environmental survey was referring to the immediate crash site with no reference to the gradient of the road in general. In these cases the drivers in the passing lane were travelling uphill (apart from the two sites that were located on crests), which meant that the drivers in the opposing direction were travelling downhill. At all other sites the road was level.

At 57% of sites the road was classified as straight, and all other sites were curved to different degrees (easy, moderate, and severe). In many cases the road was curved before and after the crash site. These horizontal curves could indicate that the visibility (or sight lines) for some drivers possibly had been reduced by the time they made the decision to overtake.

4.2.2.2 Carriageway/Lane Widths

The road carriageway and lane widths were measured across all sites (Appendix D) to establish whether any were notably less than the standard recommended width of 3.5 m. The average carriageway width was 13.27 m, with the narrowest carriageway being 11 m and the widest being 17.6 m. Transit NZ geometric design standards show a minimum carriageway width for a 3-lane highway to be 13.5 m (3 lanes at 3.5 m each, plus 1.5 m shoulders both sides), with a desirable carriageway width being 15.5 m.

Most widths were close to the standard 3.5 m, with the average lane width being 3.49 m across all measured lanes. The narrowest lane width measured was 3.2 m.

4.2.2.3 Shoulder Widths, Verge Widths and Roadside Features

The road shoulder and additional gravel widths, as well as grass verges, provide a safe escape route for drivers. If this is not present drivers cannot easily avoid an oncoming vehicle and are more likely to have a crash. The proximity of guardrails, banks, and drainage ditches also impact on the roadside space available as an escape route for drivers. Therefore, the available shoulder widths at the sites studied were examined, as were the distances to potential roadside hazards such as ditches, guardrails or banks. Minimum standard shoulder widths of highways (Transit NZ) are 1.5 m, with a desirable width of 2.5 m both sides.

On the passing lane side of the road, the sealed shoulder width for most sites was approximately 1 m (1.32 m average, ranging from 0 to 3.75 m). However, even when the additional gravel shoulder is included, few sites had sufficient width to enable drivers to pull fully off the road, with only two sites actually having an additional gravel shoulder (Appendix E). On the passing lane side, the average verge width was 1.8 m with a wide range of distances from the road edge to features such as ditches and banks (on average 2.4 m to ditches and 3.0 m to banks where present). If the sealed shoulder and verge widths are combined to give the available space for evasive manoeuvring, the average width was 3.1 m (ranging from 1.4 to 9.4 m).

On the opposing side of the road at the survey site, shoulder widths were also generally approximately 1 m (1.4 m average, ranging from 0.3 to 2.7 m). Again, few had any additional gravel shoulders. The verge widths and roadside features at each site were examined as they also impact on the amount of space that a driver has to pull off the road and avoid oncoming vehicles. On the opposing side the average verge width was 2.78 m, ranging from 0 to 7 m (substantially wider than for the passing lane side). The average distance to ditches on this side was 2.5 m (ranging from 0.9 to 7 m) and the average distance to banks was 3.7 m (ranging from 1 to 6 m). If the sealed shoulder and verge widths are combined to give the available space for evasive manoeuvring, the average width was 4.2 m (ranging from 1.5 to 8.85 m).

The average amount of space that is available to drivers to engage in evasive manoeuvring on both sides of the road appears to be substantial if drivers are prepared to use the verge area. (It is 3.1 m on the passing lane side of the road, and 4.2 m on the opposing side of the road.) This suggests that in 13 out of 21 sites drivers would have sufficient room to pull off the road in an emergency situation. (Note however that 8 of 21 sites analysed had combined shoulder and verge widths of less than 2 m.)

4.2.2.4 Sight Distances

Sight distance is defined as the length of unobstructed line of sight (or visibility) along a road available to a driver. An analysis of the sight distances at the crash sites was undertaken (Appendix G). Sight distances beyond the crash site ranged from 100 m to 1500 m, with an average of 410 m. These sight distances are estimations only, and are taken from the crash site. As such, they do not reflect the sight distance available to the driver at the point where the decision to overtake was made. Notwithstanding the inherent errors, the distances are included to give an indication of the physical road scene at the crash site.

The distance from the crash site to the start of the diverge for the passing lane, where one was present, was included because many crashes caused by overtaking in the opposing direction had occurred in the vicinity of a diverge. These data show that 9 of the 21 crash sites were within 500 m of the diverge area, and that two were located near right-turn bays.

4.2.2.5 Paintwork / Lane Markings

The paintwork on each road at the survey or crash site was examined to establish whether the drivers overtaking in the opposing direction had crossed yellow lines. As the road markings may have been changed in the period between the date of the crash and the survey date, some caution is required in interpreting these results.

A substantial proportion of drivers overtaking using a passing lane in the opposing direction crossed yellow lines to do so. Of the 21 sites surveyed, 9 (43%) involved crashes where drivers had overtaken illegally across a yellow line and one involved a driver overtaking on a dashed yellow line (Appendix H). This would indicate that the drivers had made their decision to overtake regardless of the warning indication of restricted visibility or known danger area at that location, as provided by the double yellow lines.

Of note was a crash site that had a hatched shoulder area in the opposing lane before a crest on a horizontal curve. At this site the head-on crash involved merging vehicles travelling in the opposing direction (the hatched shoulder area being used by a slower vehicle) crossing the double yellow line into the path of oncoming vehicles.

Also of note are the 43% of crashes that were located near the start of the passing bay near the diverge area, and the two crashes that occurred in the vicinity of a marked right-turn bay. It was not considered that the lane markings themselves were the cause of the crash however, but rather that the openness of the topography may have been a contributing factor.

4.2.2.6 Vehicle Speeds

Traffic speed readings were taken using Marksman LTI 20.20 and Stalker Sport laser speed guns. They were taken for vehicles travelling in either direction. Each direction was surveyed for approximately 10 minutes with the speed of all vehicles being measured continuously, to obtain a minimum 20 readings. The speed measurements were not intended to provide a comprehensive analysis of vehicle speeds, but rather to identify the general range of speeds at which vehicles were travelling in the area.

Measurements of vehicle speeds were taken to establish whether vehicles driving on the roads in the vicinity of the survey sites were significantly exceeding the posted speed limit (Appendix C). The posted speed limits for all but one site was 100 kph (with one 100 kph site restricted to 70 kph due to road works). The average speed of drivers across all 100 kph sites was 93 kph, with the lowest average speed at the 100 kph-posted sites being 81 kph and the highest being 101 kph. The average 85^{th} percentile speed across all sites was 102 kph, with the lowest 85^{th} percentile speeds at the 100 kph-posted sites being 91 kph and the highest being 109 kph. All sites showed relatively similar average and 85^{th} percentile speeds. Drivers at these sites were generally travelling within the speed limit.

4.2.2.7 Vehicle Closing Speeds

Closing speeds at each survey site were checked because of concern regarding the number of crashes that occurred in locations where sight distances appeared to be adequate, yet drivers seemed to misjudge the speed of vehicles around them.

At the survey sites, most of the passing lanes met the *NZ Manual of Traffic Signs and Markings* (MOTSAM) sight distance criteria (Transit NZ & LTSA 2000) for marking no-passing double yellow lines (Appendix I). However, in around half of the surveyed sites where there were no restrictions on passing in the opposing traffic lane, the sight distances did not meet the Establishment Sight Distance (ESD) required for overtaking movements as set out in the Austroads Rural Road Design Guide. That means, if using the Austroads ESD criteria for installing 'no passing' double lines, double yellow lines would be required for these sites. Closing speeds and times averaged at 204 kph, or 57 m/sec for all the 100 kph posted sites.

Also of note are the two sites that have very poor comparison with the ESD and the 43% of crashes that were located near fairly open topography, and where no double solid yellow no-overtaking lines were in place. These sites are worth examining further as, even when the likely variation in estimating sight distance is taken into account, the differences are significant. Looking at the site where the estimated sight distance is 33% of the Austroads ESD (SH 1 (576/10.144) Atiamuri), the opposing lane had an easy curve with very limited visibility that transitioned into a straight section of road. Survey observations led to the view that the driver had made the decision to overtake too soon, and that the downhill section of road may have influenced the decision to go ahead with the overtaking movement. Closing speeds at this site were surveyed 196 kph, or 54 m/sec.

At the site where the comparison to ESD is 45% (SH1 741/5.966, Turangarere), the closing speeds were faster, being surveyed at 219 kph, or 61 m/sec. The topography at this site was a downhill section of road and the crash site was located on a straight, which led to a moderate curve. Again, there was no yellow line in the opposing lane side. From survey observations, frustration at the long section of highway before the crash site that had little or no overtaking opportunities, the 'open' downhill area following this section, combined with the queue of trailing vehicles, may have all influenced the decision to overtake. Indeed, at the same site while the survey was in progress, a vehicle travelling in the opposing lane overtook a number of other vehicles travelling in the same direction. The overtaking driver caused emergency braking within the line of traffic when he had to re-enter the lane in a hurry because of oncoming traffic in the passing lane (i.e. traffic that was legally using the middle lane to overtake).

4.2.2.8 Traffic Volumes

Traffic volumes on the sites surveyed ranged between 4,500 vehicles per day (vpd) and 18,400 vpd, with half of the sites being over 10,000 vpd, volumes which are considered to be moderate to high for rural roads. The roads surveyed are above the 4,000 vpd level, which means that they should be built and designed to a higher standard to cope with such traffic volumes.

4.2.3 Key Themes

- Sites where crashes occurred because drivers used a passing lane to overtake in the opposing direction can generally be divided into three types:
  - Sites on downhill straight sections of road that ended in a sweeping right hand curve (in the downhill travel direction), often where a diverge for the passing lane starts. Although not specifically surveyed, the location of this type of site generally followed a section of road that had few overtaking opportunities. Around 70% of crashes occurred on such downhill sections of highway.
  - Sites on a section of road with moderate to severe curves where visibility is restricted.
  - Sites on level sections of road where either weather was a significant factor (icy patches on road), or the driver misjudged overtaking opportunity.
- In most instances drivers were travelling at or near the speed limit.
- Many of the sites were in hilly areas (62% of crashes occurred on sites with a 5% to 15% gradient).
- Most crashes occur on straights or easy curves (57% on straights).
- At many sites shoulder widths were restricted, and potential roadside hazards (such as ditches, guardrails or banks) were located close to the seal edge, giving drivers both of the overtaking vehicle and of vehicles overtaken or in the passing lane nowhere to go if they had misjudged the overtaking manoeuvre. Where verges were available, these did not seem to be used as an escape route, possibly because drivers may be more reluctant to use unsealed surfaces at open-road speeds where sealed shoulders are not present.
- Drivers who had crossed double yellow lines to attempt the overtaking manoeuvre accounted for 43% (based on environmental surveys of the lane markings currently on the road).
- An analysis of closing distances showed that 9 of the 21 sites (43%) did not meet ESD standards.

4.3 Consultation with Transit Regional Engineers

4.3.1 Methodology

Managers and engineers for the North Island Transit NZ regions were sent details of crashes that had occurred in their regions where drivers used a passing lane to overtake in the opposing direction.

They were asked for their opinions on the likely factors that may have contributed to the crashes as well as possible solutions to prevent or lessen the occurrence of crashes of this type. Details such as traffic volume and carriageway cross-section dimensions were also requested.

4.3.2 Key Themes

The following issues were highlighted by Transit engineers during the consultation:

4.3.2.1 Possible factors contributing to a crash

- Driver frustration, on reaching downhill straight sections of highway (alongside opposite passing lanes), which are often the first opportunity for drivers to pass slow vehicles after a long section with few or no overtaking opportunities.
- Many crashes caused by drivers taking risks or '*stupid driving*'.
- Human factors are more of an issue than engineering.
- Misunderstanding the marking and signage about overtaking. (Transit Waikato in particular indicated such concern.)

4.3.2.2 Possible solutions suggested by Transit Engineers

- Provide more frequent passing lanes to reduce driver frustration.
- Improve the advance signage leading up to passing lanes.
- Install double yellow 'no passing' lines on all 3-lane sections of highway.
- Use wider double yellow paint markings with vibraline (reported to work well in areas where this treatment has been used).
- Improve traffic education.

Generally Transit engineers appear to consider that more overtaking opportunities would assist safety by reducing driver frustration and inappropriate overtaking. They had concern about overtaking across a centreline on multi-lane roads, and expressed a desire to be able to legally prevent such a move with measures such as double yellow lines.

4.4 Survey of Driver Understanding of Yellow No-Overtaking Lines

4.4.1 Survey Design

To assess the understanding of the general driving public regarding yellow no-overtaking lines, a survey of drivers was undertaken. A sample of 31 drivers were surveyed, ranging in age from 16 to over 65 years, and fairly evenly split between males and females. The drivers for the survey were those recruited for the simulator testing of overtaking lane designs carried out at Waikato University (see Section 5.1).

Each driver was presented with a range of yellow line configurations and asked to assess the safety and legality of attempting to overtake. The aim was to assess whether drivers understood the required behaviour at different 'yellow line' scenarios. The term 'safety' was left undefined and drivers were left to base their assessments of safety on their own criteria. A questionnaire was used.

The survey was designed to assess respondent drivers' understanding of a range of yellow line configurations that are commonly seen on New Zealand roads. The configurations surveyed (Figures 4.3–4.7) were:

- Two-lane road with solid yellow no overtaking line on respondent driver's side;
- Three-lane road with double lane in driver's direction with solid yellow no-overtaking line on respondent driver's side;
- Two-lane road with double solid yellow no-overtaking lines;
- Two-lane road with solid yellow no-overtaking line on opposing side;
- Two-lane road with dashed yellow line on respondent driver's side.

The survey aimed to assess two issues:

- How safe respondents considered it was to attempt to pass the vehicle in front, given the situation pictured;
- Whether it was legal to attempt to pass the vehicle in front, given the situation pictured.

Respondents were told to assume that they had sufficient visibility and that no vehicles were approaching in the opposing direction.

4.4.2 Survey Results

Figure 4.2 shows the safety ratings obtained from respondents' replies for each yellow line configuration. The figure provides the mean rating as well as the maximum and minimum ratings. The rating scale was configured from 0 representing a rating of very unsafe to 10 representing a rating of very safe. Responses to each of the five yellow line configurations (illustrated in Figures 4.3–4.7) are discussed below.

1. **Two-lane road with solid yellow no-overtaking line on respondent driver's lane only** (Figure 4.3)

The mean safety rating for this configuration was 1.7, though ratings ranged from 0 to 5. This result indicates that respondents generally felt that it was unsafe to overtake under this circumstance. However, a few respondents, all drivers under the age of 29, gave this configuration a moderate safety rating (e.g. a rating of 4 or 5 out of 10).

In addition, 96.8% of respondents correctly indicated that it was illegal to overtake under these circumstances. One respondent (3.2%) indicated that it was legal.

2. **Three-lane road with double lane in driver's direction with solid yellow no-overtaking line on respondent driver's lane only** (Figure 4.4)

This configuration was the one that respondents rated as safest. Almost all respondents rated this scenario as very safe, with the mean rating being 9.2. Scores ranged from 8 to 10 indicating a strong consensus between respondents.

In terms of legality, 96.8% of respondents indicated that it was legal to overtake under these circumstances. One respondent failed to answer the question.

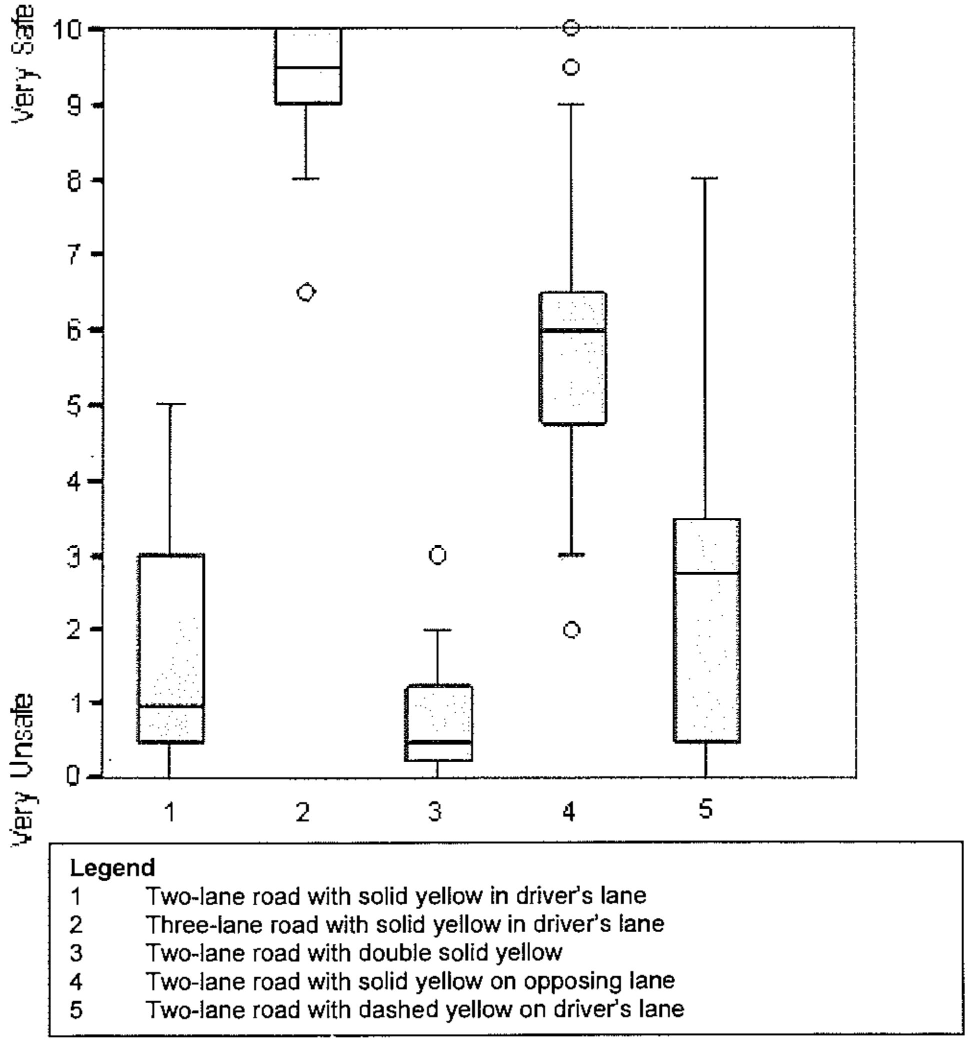

Figure 4.2 Safety ratings for yellow line configurations.
Note: Confidence interval of 95%. Outliers outside the confidence interval are indicated by circles. Ratings range from 1 very unsafe, to 10 very safe.

3. Two-lane road with double solid yellow no-overtaking lines (Figure 4.5)

This configuration was the one that respondents rated as the most unsafe for overtaking. The mean safety rating was 0.9, and ratings ranged from 0 to 2 indicating a strong consensus between respondents.

In addition, 100% of respondents stated that it was illegal to overtake under these circumstances.

4. Two-lane road with solid yellow no-overtaking line on opposing lane only (Figure 4.6)

The mean safety rating for this yellow line configuration was 5.9, though rating scores ranged from 2 to 10. These ratings indicate that opinions differed markedly in terms of how safe it is to attempt to overtake under these circumstances. Note that five of the six respondents who rated overtaking as very safe under these circumstances were male.

In terms of legality, 100% of respondents knew that it was legal to overtake when there was a solid yellow line in the opposing direction.

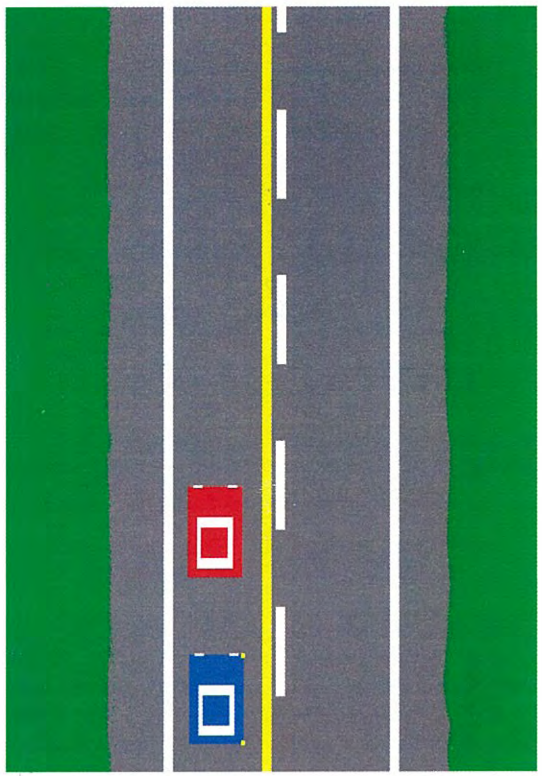

Figure 4.3 Two-lane road with solid yellow no-overtaking line on driver's side only.

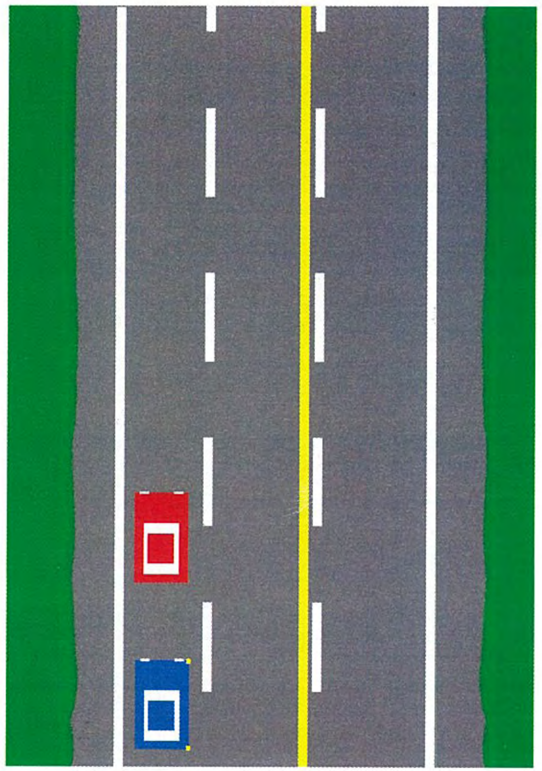

Figure 4.4 Three-lane road with double lane in driver's direction with solid yellow no-overtaking line on driver's side.

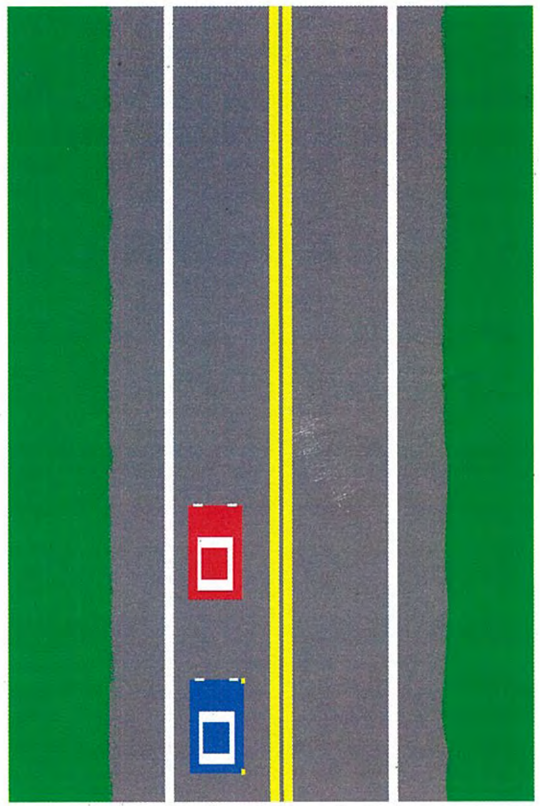

Figure 4.5 Two-lane road with double yellow solid no-overtaking lines.

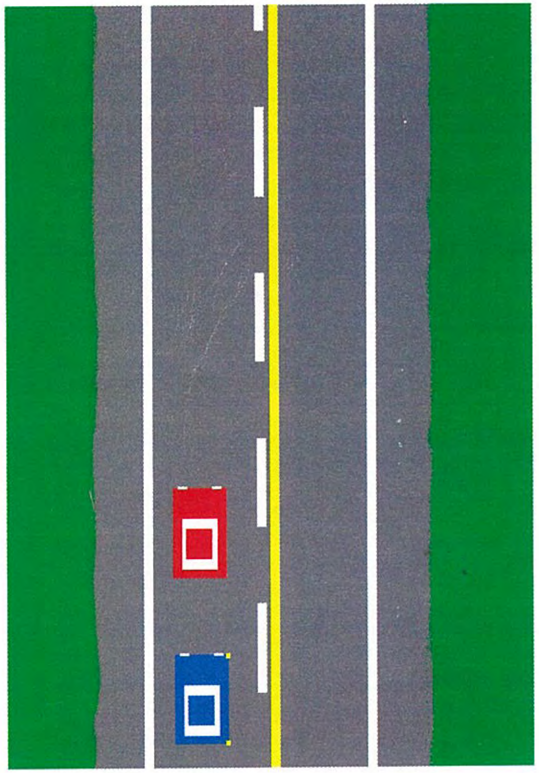

Figure 4.6 Two-lane road with solid yellow no-overtaking line on opposing lane only.

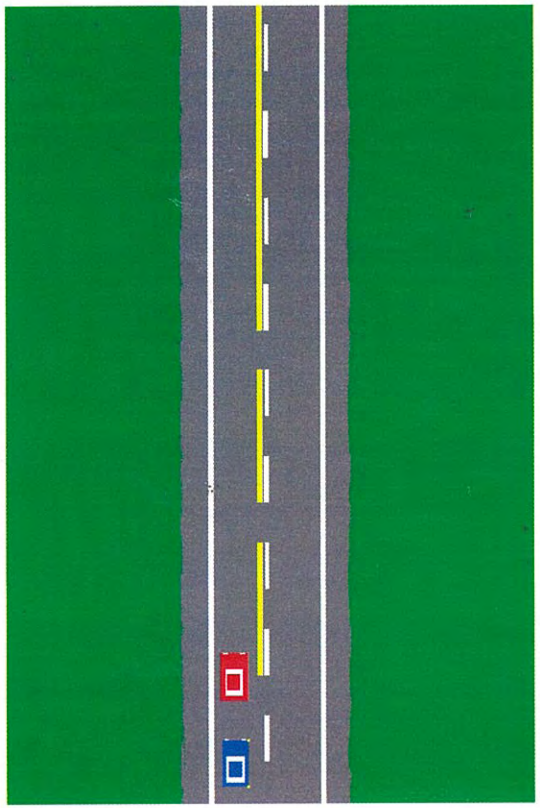

Figure 4.7 Two-lane road with dashed yellow line on driver's lane only.

5. **Two-lane road with dashed yellow line on respondent driver's lane only** (Figure 4.7)

The dashed yellow line configuration resulted in the broadest range of responses. Many respondents seemed uncertain regarding both the safety and legality of overtaking in this situation. The mean safety rating was 2.6 with ratings ranging from 1 to 8.

Respondents also seemed uncertain about whether it was legal to overtake, with 45.2% stating it was legal and 51.6% stating it was illegal. One respondent did not answer this question.

4.4.3 Key Themes

The aim of the survey of drivers was to assess whether respondents understood road rules relating to yellow lines. The results of this survey clearly show that respondents have a good understanding of the level of safety (for an overtaking manoeuvre) suggested by the lane markings presented.

The results of the survey suggest that males and younger drivers are a little more likely to rate overtaking as safe in scenarios where overtaking is legal but requires the driver to exercise their judgement about whether it is safe to overtake. However, the overwhelming number of drivers seemed to have a good understanding regarding when it is legal to attempt to overtake another vehicle.

The only exception to this related to the dashed lines scenario where respondents showed a high degree of uncertainty regarding both the safety and legality of attempting to overtake under these circumstances.

4.5 Conclusions

This Stage 4 of the research focused on the overtaking crashes that occurred when drivers attempted to use a passing lane to overtake in the opposing direction. An examination of the CAS crash records showed that, of the crashes identified as taking place in passing lanes, this type of crash resulted in the highest number of fatal and serious injury casualties. Thus it was reasoned the greatest gain with regards to safety could be made if common causal factors that could be addressed were found.

As stated in Section 4.1, the research concentrated on four separate areas:

- Further detailed examination of the CAS crash data (Section 4.1);
- Site visits to 21 of the 40 sites to conduct structured environmental surveys of the external conditions of the crash site (Section 4.2);
- Obtaining comments on this type of crash from Transit Regional Engineers (Section 4.3); and
- A survey of drivers by questionnaire to establish the level of understanding of the yellow no-overtaking lines (Section 4.4).

4.5.1 Methodology for Analysing Common Contributing Factors of Crashes

The methodology, which used detailed analysis of CAS reports, analysis of environmental external conditions of sites, consultation with Transit roading and traffic engineers, and survey of driver understanding, was considered to be the most comprehensive and in-depth way to investigate possible causes for 'overtaking in the opposing lane' crashes. The key themes of the four steps are summarised here.

4.5.1.1 Detailed Examination of CAS Crash Data

Analysis of the crash reports showed that the demographics of drivers for these types of crashes were mainly people aged 25 to 45 years, with the largest group of drivers involved being males aged 25 to 45 years (35.5%). The crash data also indicated that, generally, poor road conditions or weather were not major contributors to these crashes, although two crashes did occur where icy conditions appeared to be the primary contributing factor. Of interest was that approximately half the crashes involved overtaking longer vehicles, where the vehicle being overtaken was either a truck, heavy vehicle, or vehicle towing a trailer or boat.

4.5.1.2 Analysis of Environmental Surveys of Crash Sites

Road geometry surveys of the external conditions of the crash sites showed that around 43% of crashes were located near the start of the passing lane near the diverge area, and that two occurred by a right-turn bay.

Road gradient & curvature, as expected, affected crash rates. The most common scenario was a downhill, straight section of road that ended with an easy horizontal curve, with reasonable sight distances available.

Other typical scenarios were sections of road with moderate to severe horizontal curves, which had limited sight distances available, including two sites located on a crest with very restricted sight distances. Double yellow no-overtaking lines were present at around 43% of sites, and four sites with restricted sight distances did not have double yellow lines.

Paintwork/Lane markings that were misleading was considered to be a factor at one site surveyed, where a hatched shoulder with no clear signage or markings for safe merging was a contributing factor in a head-on crash.

Typical *road layout* (cross-sections) at the crash sites were 3 lanes, each approximately 3.5 m wide, which is the current standard highway width; with sealed shoulders averaging 1.32 m, which is less than the minimum Transit NZ standard of 1.5 m (the desirable Transit NZ width is 2.5 m). Distances to physical obstructions, where present, were typically 2.5 m to ditches from the edge of seal, and 3.7 m to banks.

A shoulder width of 1.32 m was noted to provide barely enough room for a vehicle to get off the highway in an emergency situation on a predominantly high-speed rural road. With two 3.5 m lanes on a passing lane layout, the additional 1.32 m will give a total of 8.32 m which gives approximately 0.5 m nominal clearance for each 'standard' vehicle. (If heavy vehicles are involved, the clearance between vehicles will be less.) Shoulder widths should be desirably 2–2.5 m.

Driver behaviour observed at the crash sites showed that almost all drivers kept within the posted speed limits, with average speeds of 93 kph and 85th percentile travel speeds of 102 kph. At the sites with 100 kph posted speed limit, downhill speeds were mostly slower than uphill speeds in the passing lane.

Closing speeds (between downhill and uphill traffic) averaged 204 kph, or 57 m/sec for the 20 sites that have 100 kph posted speed limits.

Sight distances at many of the 'straight, downhill on to easy curve' sites, appeared to be satisfactory, and indeed most met the New Zealand standard set out in MOTSAM. However, when compared to the Austroads recommended sight distances for establishing an overtaking opportunity, about half did not meet the desired distance. It was not possible to establish where the drivers involved in the crash made their decision to overtake, and thus the sight distances observed may not accurately reflect the situation at the time of the crash. The distances, however, give a broad indication of how distances compare against the New Zealand and Australian standards.

Traffic volumes over the sites surveyed ranged between 4,500 vpd and 18,400 vpd, with half the sites being over 10,000 vpd (i.e. moderate to high volumes).

4.5.1.3 Consultation with Regional Engineers

Regional engineers in the North Island Transit regions indicated driver frustration, poor judgement, risky behaviour, and misunderstanding some signs and markings as being causal factors for 'overtaking in the opposing lane' type crashes.

4.5.1.4 Survey of Drivers' Understanding of Yellow No-overtaking Lines

The questionnaire survey of drivers on their understanding of the yellow 'no overtaking' lines clearly showed that most of them understood the legality of these markings.

Males and younger drivers appeared to be slightly more likely to overtake in situations where the markings showed the overtaking was legal but required the driver to exercise their judgement as whether it was safe to do so or not. Interestingly, this group represented the largest number of drivers involved in these types of crashes (see Section 4.1, Detailed Analysis of CAS Crash Reports).

The dashed yellow approach 'no-overtaking' lines caused some confusion among the questionnaire respondents with regards to the safety and legal situation of overtaking in this situation.

4.5.2 Issues Investigated Concerning Causes of Crashes

The methodology applied in this part of the research, which led to an examination of all the available data, points to several issues that may contribute to these types of crashes, i.e. crashes related to overtaking in the opposing direction. The conclusions are described in this section.

4.5.2.1 Driver Attitude and Behaviour

Interestingly, the group most often involved in these types of overtaking crashes (males aged 25-45 years) were also the group that were somewhat more likely to rate passing as safer in situations where it was legal to do so but driver judgement was required (yellow line survey). This perhaps indicates that this group is slightly more inclined towards risk taking.

Also notable is that 22.5% of drivers left the scene of the crash without giving their details (CAS analysis). Additionally, in 43% of crashes drivers had illegally crossed double yellow lines to perform the overtaking manoeuvre. Engineers felt that driver frustration played a part in these crashes and that the frustration may be related to the lack of overtaking opportunities.

4.5.2.2 Overtaking Longer Vehicles

A total of 47.5% of crashes involved drivers attempting to overtake longer vehicles. Lerner et al. (2000) found that about one-third of drivers overestimate the time they have available during a passing manoeuvre and underestimate the time required to pass a vehicle, especially when that vehicle is a truck. When time-available and time-required judgements were combined, 58% of drivers' estimates were safety-negative errors for passing a truck, and 26% for passing a car. In several of the crashes examined, drivers seemed to have underestimated the time required to pass.

4.5.2.3 Engineering Road Design Factors

Road designs that may have contributed to a number of crashes included a lack of an 'escape route' if errors in driver judgement were made. Sealed shoulders were rarely of a width that a driver could move out of the way to avoid a crash, and sloping verges, ditches and banks added to the unforgiving nature of the road sections that were surveyed in this study.

4.5.2.4 Sight Distances

At some sites, sight distance may be inadequate. Analyses indicate that perhaps the current criteria for installation of double yellow no-overtaking lines do not adequately address the specific problems and factors that occur with overtaking manoeuvres on three-lane sections of road.

The MOTSAM criteria for implementation of double yellow no-overtaking lines are where visibility is less than 330 m (from an eye-level height of 1.15 m to an object of 1.15 m height), and where the length of the restricted visibility exceeds 80 m. MOTSAM indicates that these criteria should be used for deciding on the type of markings for the lane opposing the passing lanes, i.e. whether it is marked as a white dashed centreline or a solid yellow no-overtaking line. Given the closing speeds measured on passing lanes (at speeds that generally did not exceed the posted speed limit), 330 m is considered less than adequate in the passing lane situation. This length of 330 m is equivalent to just under 6 seconds of driving time.

For the design speed of 100 kph, Austroads shows the Establishment Sight Distance (ESD) to be 920 m (or 17.8 sec.), and the Continuation Sight Distance (CSD), i.e. the crucial time period that a driver has when making the decision to continue overtaking or to pull back into the line of traffic, being 430 m (7.2 sec.). Thus in the passing lane situation, where there is some confusion with using the centre passing lane to overtake in the opposing direction, the MOTSAM criteria for installing double yellow 'no-overtaking' lines does not appear to be appropriate.

Factors that influence the available sight distance in relation to the closing speeds are: the point at which the driver made the decision to overtake, and whether the overtaking vehicle was the first vehicle to be trailing the slower driver or the second or third (affecting the required sight distances). Both these factors are generally unrecorded and therefore unknown. Thus some additional form of warning to drivers may be needed at sites where closing speeds indicate greater sight distances are required, and the appropriateness of the current criteria for installation of double yellow 'no-overtaking' lines should be reviewed.

4.5.2.5 Other Factors

Factors that may also have contributed to the crashes analysed include:

- Misjudgement of the speed of the oncoming vehicle;
- Misjudgement of the lane the oncoming driver was using, especially at sites that were close to the diverge start section of a passing lane (in the opposing direction);
- Misjudgement of the time taken to overtake a vehicle;
- Unable to see a vehicle following another because of the horizontal curve, and therefore not expecting that vehicle to move into the centre passing lane;
- Frustration caused by trailing slower vehicles through a length of highway where there are few, or no, overtaking opportunities;
- The 'openness' of three lanes on a downhill (for the opposing traffic) section of straight road may give a false message that the length of highway in which to overtake is longer than it actually is;
- Misleading paintwork;
- Not driving to suit the road conditions.

4.6 Suggested Changes[4] to Lane Design

- Increase passing lane opportunities to reduce driver frustration and subsequent increased risk taking. *(This suggestion results from consultation with Transit regional engineers and environmental survey observations.)*

- Consider widening the opposing lane to provide overtaking opportunities for downhill traffic. *(This follows the previous suggestion and is aimed to reduce driver frustration by providing a safe place to overtake on the downhill sections of road in the opposing direction to the passing lane.)*

[4] Suggestions are in normal type, sources of suggestions are in italics and parentheses.

- Widen sealed shoulders to 2–2.5 m (Transit NZ standard gives an absolute minimum of 1.5 m) to provide an emergency 'escape route' for drivers involved in potential crashes on these predominantly high-speed rural roads. The installation of marker posts approximately 1 m outside the lane edgeline could be considered to prevent these shoulders being used by slow vehicles. *(From Crash Data where records stated 'nowhere to go' as a causal factor, and environmental survey of external conditions which confirmed that, in many cases, shoulder widths were minimal. Overseas industry consultation recommends shoulder widths that are consistent with those provided before and after the passing lane section of road.)*

- The closing speeds between downhill opposing lane and uphill passing lane traffic are high, with a closing rate of 57 m/sec (as measured in the Environmental Survey of external conditions). For this reason the installation of double yellow Vibraline no-overtaking lines may be worth considering at all high-risk 3-lane sections of road. *(This suggestion is a result of consultation with Transit engineers, and environmental survey observations. Overseas industry consultation recommends that no-overtaking lines should be installed at least at all merge and diverge and other hazardous areas.)*

- Where traffic volumes are high, consider installing a solid median barrier between the opposing lane and the passing lane, and consider the possibility of installing 2- + 1-lane treatments (as used in Sweden). *(This suggestion is aimed at prohibiting overtaking in the opposing direction where overtaking opportunities are reduced. The environmental survey observations, surveys on the understanding of double yellow 'no-passing' lines, and crash data investigations have shown that painted 'no-passing' lines are often deliberately ignored, especially where driver frustration is high.)*

- Install warning signage at potentially hazardous areas where some confusion about actual available sight distances is likely, and where there is some uncertainty as to which lane vehicles will travel in. *(From environmental survey observations and consultation with Transit engineers.)*

- Increase education to the motoring public on safe overtaking. *(From Transit engineer consultation.)* Install warning signs at locations where negative weather conditions, such as ice, occur. *(From Crash Data investigation and environmental survey observations.)*

- Remove hatched shoulders that may be used as 'pseudo' passing lanes (often by slow vehicles), or treat the merge of such areas in the same manner as passing lane merges. Otherwise, reconfigure the 'pseudo' passing lanes as formal passing lanes. *(From environmental survey observations and Steering Committee comments.)*

5. Passing Lane Merge Design

To examine the impact of passing lane merge design on driver behaviour, the research group, in consultation with the Steering Committee, decided that a simulator-based study of various merge designs would be conducted as Stage 4 of the study. The following section provides a full outline of the research methodology, results, and suggested changes to overtaking lane design derived from this study.

5.1 Experimental Methodology

5.1.1 Selection of Treatments

5.1.1.1 Passing Lane Site Selection

To ensure that the merge sites used in the study were as realistic as possible, actual roads were reproduced (using RGDAS[5] data), and the simulated passing lanes were based on existing on-road passing lanes. The road geometry depicted in the simulation was an accurate representation of the Kaimai Range portion of SH29. In addition to this section of SH29, a 5-kilometre length of road was inserted in the simulation (at one end) to create sufficient road length so that the fourth passing lane design could be included. TERNZ has previously used this route for simulating and testing passing lanes (Charlton et al. 2001) and they found it provided a good representation of general passing lane scenarios.

The stretch of road was simulated in both directions (eastbound and westbound) giving two complete simulated roads. Four passing lanes were placed on the road in each direction: three of them in each direction were based on existing passing lanes, and the fourth passing lane was developed to fulfil the experimental requirements. The passing lanes were selected to represent a range of road geometries and lengths, as can be seen in Table 5.1. The traffic placed on the simulated road represented 14,000 passenger car units (pcu) per day. The traffic presented on the simulator was a mixture of cars, light trucks, and heavy vehicles.

5.1.1.2 Merge Area Treatment Selection

The research group, in consultation with the Steering Committee, decided to investigate two design issues related to passing lane merges. They were:

- Road merge geometry;
- Paintwork at merges.

Road merge geometry

Issues regarding the geometry of the merge areas that had been highlighted in the earlier TERNZ research (Charlton et al. 2001) include the effect of merge taper length on driver behaviour. As a result two design issues were investigated: manipulation of the taper length, and the termination point of the lane line[6]. The early termination of the lane line increases the length of the merge zone in a way that is subtly different from changing the physical taper length.

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[5] RGDAS – Road Geometry Data Assimilation System.

[6] Lane line – dashed white paint line separating two passing lanes.

Paintwork at merges
The second design issue investigated different road markings and perceptual countermeasures at merge areas, and the effect that these may have on driver behaviour. A number of treatments were selected, based on research conducted in Australia on using paintwork to reduce speed (Godley et al. 1999), and on consultation with an experienced traffic engineer and the members of the Steering Committee to ensure that the treatments were appropriate for implementation at merge areas.

5.1.2 The University of Waikato/TERNZ DS9 Driving Simulator

The 3-D simulation of the road was presented on a desktop driving-simulation tool using measured 3-D road geometry (from the Transit RGDAS database) to specify the roadway geometry. The road markings, road signs, traffic, and sight angles were modelled as 3-D objects and placed along the simulated roadway. The simulated scenes were presented in panorama across three display screens: one 53.34 cm (21 in.) and two 43.18 cm (17 in.) monitors, affording approximately 130° effective field of view at a frame rate of 150 frames per sec. Navigation through the simulation was by means of a steering wheel and foot pedal controls. Movement through the simulation was governed by an interactive non-linear multi-body vehicle dynamics model.

Pictures of all of the treatments developed and tested are shown in this chapter. They show the oblique scans and screen shots used in the Driving Simulator for the experimental methodology.

5.1.3 Experimental Design and Procedure

5.1.3.1 Design

Because of the number of possible design combinations, (road geometry factored with paintwork), a full factorial experimental design was not practical. Therefore, an additive factors design approach was taken, whereby each alternative treatment differs from another in only one design aspect, resulting in an incremental increase in the complexity of designs. As a result, each treatment alternative could be compared with the treatments directly before and directly after it.

A within-subjects experimental design was used to minimise the effects of variations in individual driver behaviour. Each treatment was duplicated at two sites to ensure that behavioural artefacts related to the nature of a particular site could be minimised. Thus, a total of 16 different treatment–site combinations were designed and tested. The experimental design is presented in Table 5.1, and illustrated in Figures 5.1 and 5.2. (Note that the Validation treatment is not included in Section 5.2, as it was treated as a separate analysis.)

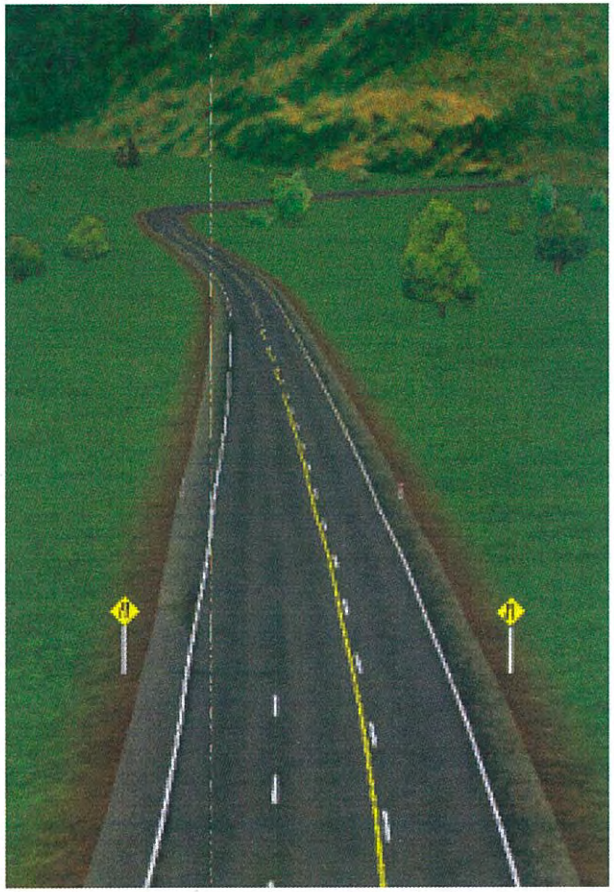
Table 5.1 Experimental design and merge treatments for a range of road geometry and paintwork treatments.

		Comparison	
Expt. Design	**Design Aspect of Interest**	**Duplicate Treatments**	**Duplicate Treatments**
	Blind Geometry	Control 1 & Control 2	Geometry 2 & Geometry 6
	Taper Length	Geometry 2 & Geometry 6	Geometry 1 & Geometry 5
	Early Lane Line Termination	Geometry 2 & Geometry 6	Geometry 3 & Geometry 7
	Double Herringbone – Long Taper	Geometry 2 & Geometry 6	Paint 2 & Paint 6
	Double Herringbone –Short Taper	Geometry 1 & Geometry 5	Paint 1 & Paint 5
	Right Herringbone – Short Taper	Geometry 1 & Geometry 5	Paint 3 & Paint 7
Treatments		**East**	
		Geometry Treatments	**Paint Treatments**
	Site 1 – Length 2.69 km	*Geometry 1* Blind Merge Short Taper (75m) Standard Lane Line	*Paint 1* Blind Merge Short Taper (75m) Standard Lane Line Double Herringbone
	Site 2 – Length 0.93 km	*Geometry 2* Blind Merge Long Taper (165m) Standard Lane Line	*Paint 2* Blind Merge Long Taper (165m) Standard Lane Line Double Herringbone
	Site 3 – Length 1.09 km	*Validation 1* SH29 Validation Lane Straight Merge Taper (125m) Standard Lane Line	*Validation 2* SH29 Validation Lane Straight Merge Taper (125m) Standard Lane Line
	Site 4 – Length 1.61 km	*Geometry 3* Blind Merge Long Taper (165m) Early Lane Line (-55m)	*Paint 3* Blind Merge Short Taper (75m) Standard Lane Line Right Herringbone
		West	
		Geometry Treatments	**Paint Treatments**
	Site 5 – Length 3.15 km	*Geometry 5* Blind Merge Short Taper (75m) Standard Lane Line	*Paint 5* Blind Merge Short Taper (75m) Standard Lane Line Double Herringbone
	Site 6 – Length 3.10 km	*Geometry 6* Blind Merge Long Taper (165m) Standard Lane Line	*Paint 6* Blind Merge Long Taper (165m) Standard Lane Line Double Herringbone
	Site 7 – Length 2.11 km	*Geometry 7* Blind Merge Long Taper (165m) Early Lane Line (-55m)	*Paint 7* Blind Merge Short Taper (75m) Standard Lane Line Right Herringbone
	Site 8 – Length 1.05 km	*Control 1* Straight Merge Long Taper (165m) Standard Lane Line	*Control 2* Straight Merge Long Taper (165m) Standard Lane Line

Note: oblique scans and screen shots of plan views of the treatments are shown in this chapter as follows:

Figure 5.1 – Control treatment
Figure 5.2 – Validation treatment
Figures 5.13, 5.14, 5.18 – Geometry treatments
Figures 5.22, 5.26, 5.30 – Paint treatments

Figure 5.1 Oblique scan (left) and screen shot of the plan view (right) of the simulated control treatment.



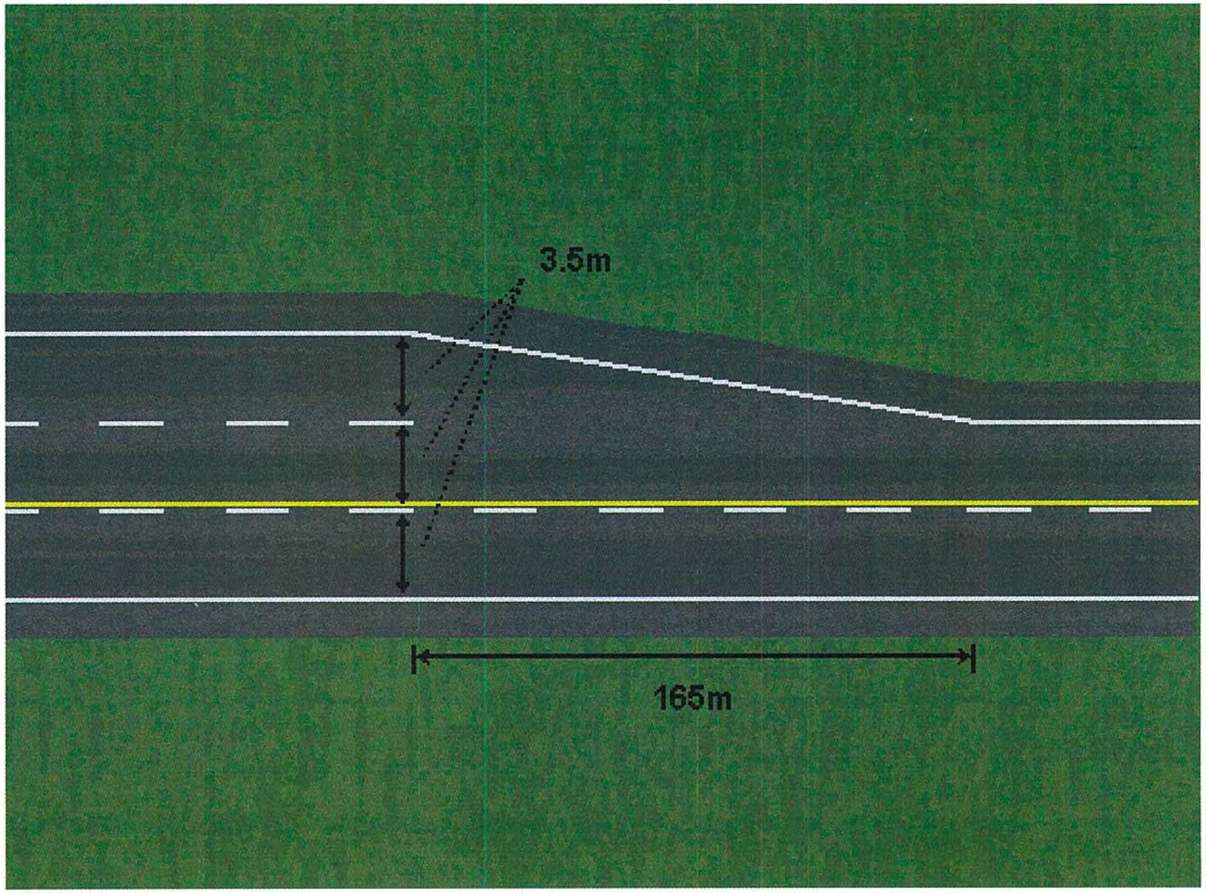
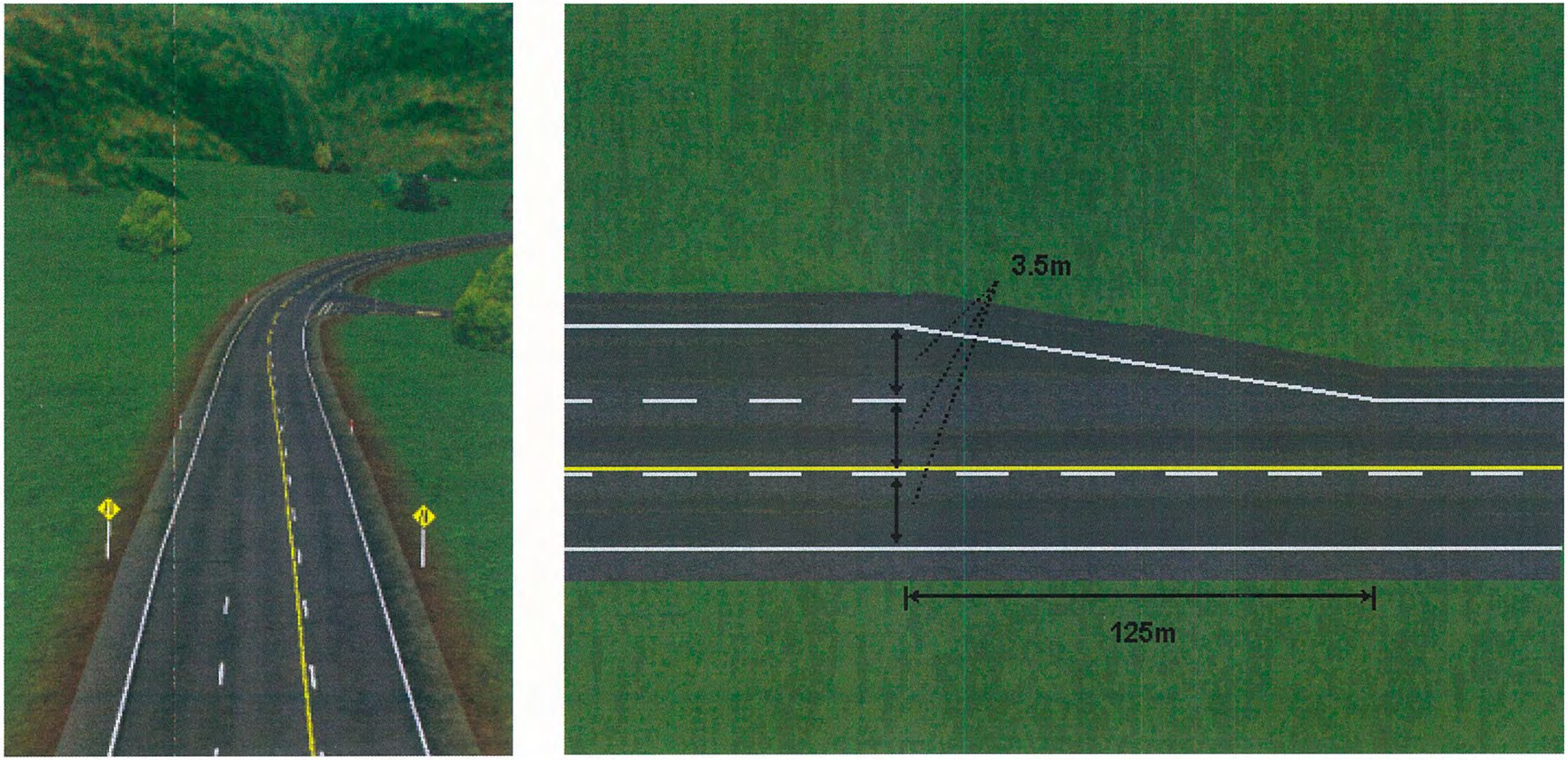


Figure 5.2 Oblique scan (left) and screen shot of the plan view (right) of the simulated validation treatment.



5.1.3.2 Procedure

A total of 31 participants took part in this study. The group included 16 men and 15 women ranging in age from 17 years to over 65 years. The distribution of participant ages, gender, kilometres driven per week, including open road kilometres, are outlined in Table 5.2. The participants were selected from volunteers (including teachers and parents) from the Tamahere Primary School, and the school received a $40 donation for each participant who took part in the study.

Participants drove two simulated roads, one in an eastward direction and one in a westward direction. One of the roads included the road geometry treatments and the other contained the paint treatments. The order of presentation of the treatment conditions was counterbalanced across all participants.

Participants were instructed to drive the simulated vehicle as they would normally drive their own car. They were further instructed to follow the traffic directives (speed limits and signage) as they normally would. Participants were able to complete a practice track for up to 10 minutes before driving in the experiment proper. This ensured that participants were comfortable with driving the simulated vehicle before beginning the experiment. The experiment took approximately two hours.

Table 5.2 Demographics of the participants in the simulator-based study.

Age (years)	Male	Female	Average Km/Week*	Average Km Open Road/Week*
15-19	2	3	148	17
20-29	2	2	223	36
30-39	4	5	381	52
40-49	4	3	399	39
50-59	2	0	325	48
60-64	0	0	0	0
65 or older	2	2	193	3

*Km/week – number of kilometres driven per week, including those on open roads.
*Km open road/week – number of kilometres driven on the open road at >100 kph per week.

5.1.3.3 Driver Behaviour Measures

Performance measures of the participating drivers were taken from five locations within the merge. These were 500 m from the beginning of the merge, 200 m from the beginning of the merge, pre-merge (the beginning of the merge taper), post-merge (the end of the merge taper), and 500 m from the end of the taper. These measurement locations are indicated in Figure 5.3.

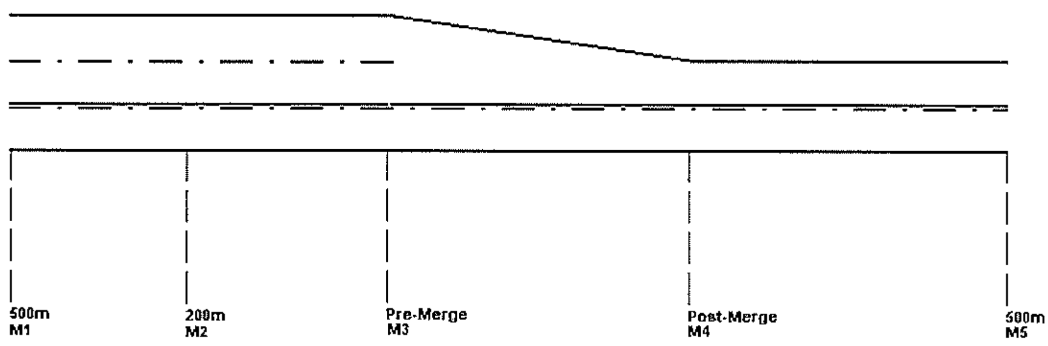


Figure 5.3 Locations of measurements taken for the driving behaviour measures on the simulated road.

5.2 Results

The results of this study were analysed to answer the following four key questions about the effects of various treatments on driver behaviour:

- What was the effect of a blind merge compared to a straight merge?
- What was the effect of a short merge taper compared to a long taper of 165 m (Austroads standard)?
- What was the effect of an early termination of the lane line compared to the standard that is currently on road?
- What were the effects of the paint treatments on driver behaviour?

5.2.1 Overall Effects of Participant Gender, Age, and Track Driven[7]

First, because data was collected at two sites for each treatment, and in order to minimise behavioural artefacts related to the nature of a particular site, these sites were analysed before combining the data to ensure that they were not significantly different. Overall effects of age and gender were also considered within this analysis. Figures 5.4, 5.5, and 5.6 show the driving performance in terms of average speeds, average lateral displacement[8], and average headway[9] afforded by the two tracks, averaged across all treatment types at all five measurement locations (M1 to M5 on the X-Axis).

[7] 'Track driven' refers to the one of the two sets of combined simulation roads that the participant drove and consisted of an East geometry road combined with a West paint road or an East paint road combined with a West geometry road (where geometry/paint refers to the type of treatments tested on that road).

[8] 'Lateral displacement' is measured from the centreline (if the participant crosses into the opposing lane, they will have negative lateral displacement), and the value describes the distance from the centreline in metres.

[9] 'Headway' is the time lag between back of the lead vehicle to front of a following vehicle, measured in seconds.

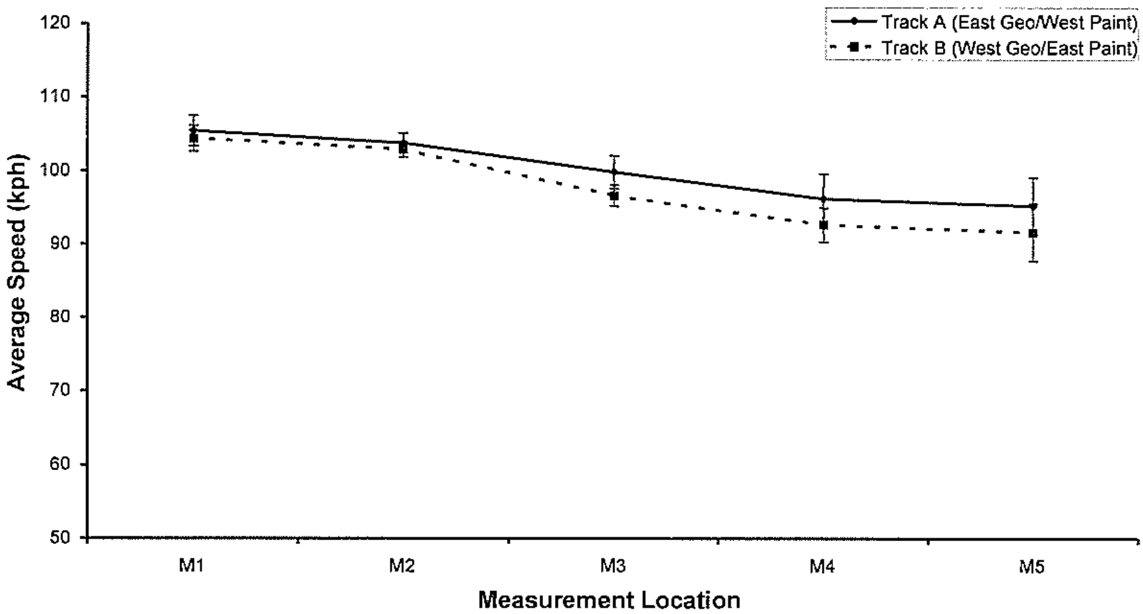


Figure 5.4 Average speed across the two sets of tracks.

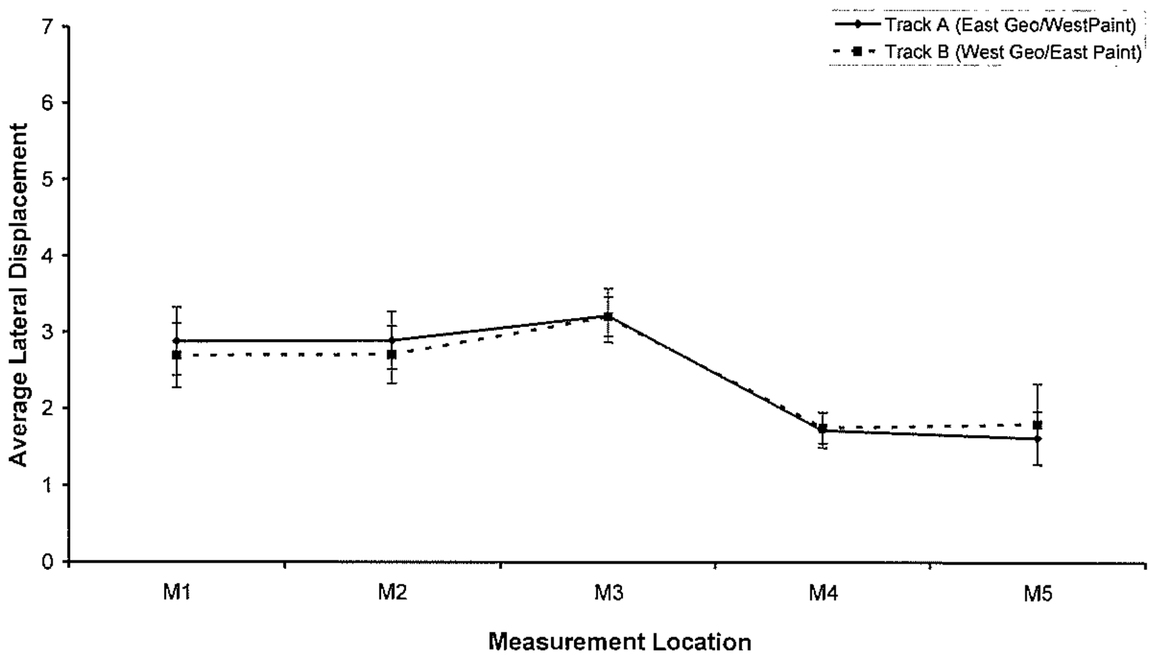


Figure 5.5 Average lateral displacement across the two sets of tracks.

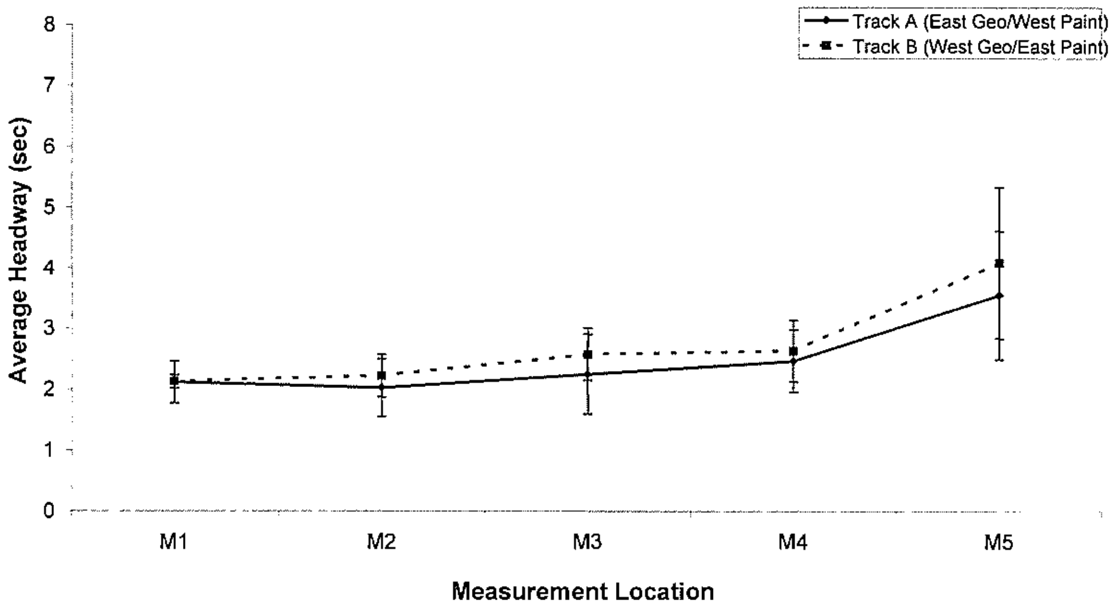


Figure 5.6 Average headway across the two sets of tracks.

A repeated-measures multivariate analysis of variance (known as MANOVA) was conducted which indicated that no significant main effects or interactions were associated with participants' age, gender, or treatment type for any of the driving variables measured ($Fs < 1.16$, $p > 0.10$). In addition, no significant site-specific or order effects on any of the driving variables were measured ($F(1,29) = 1.155$, $p > 0.10$). Therefore, the paired tracks were combined for further analysis.

5.2.2 Effect of Blind v Straight Merges

One of the key questions in this study was the impact that merges located on blind corners have on driver behaviour. Therefore, analyses were conducted comparing sites with blind merges to a control site with a straight merge. Figures 5.7, 5.8, and 5.9 provide comparisons of average driver speed, lateral displacement, and headway respectively at the blind and straight sites.

A MANOVA indicated that a significant treatment x position x measure interaction existed for this comparison ($F(8,23) = 7.286$, $p < 0.001$).

Considering the speed data only, a MANOVA showed a significant treatment x position difference ($F(4,27) = 8.072$, $p < 0.001$) indicating that the effect of the blind geometry was greater towards the end of the passing lane merge. As Figure 5.7 shows, driver speeds were higher at the blind merge than at the straight merge at M3, M4, and M5 locations.

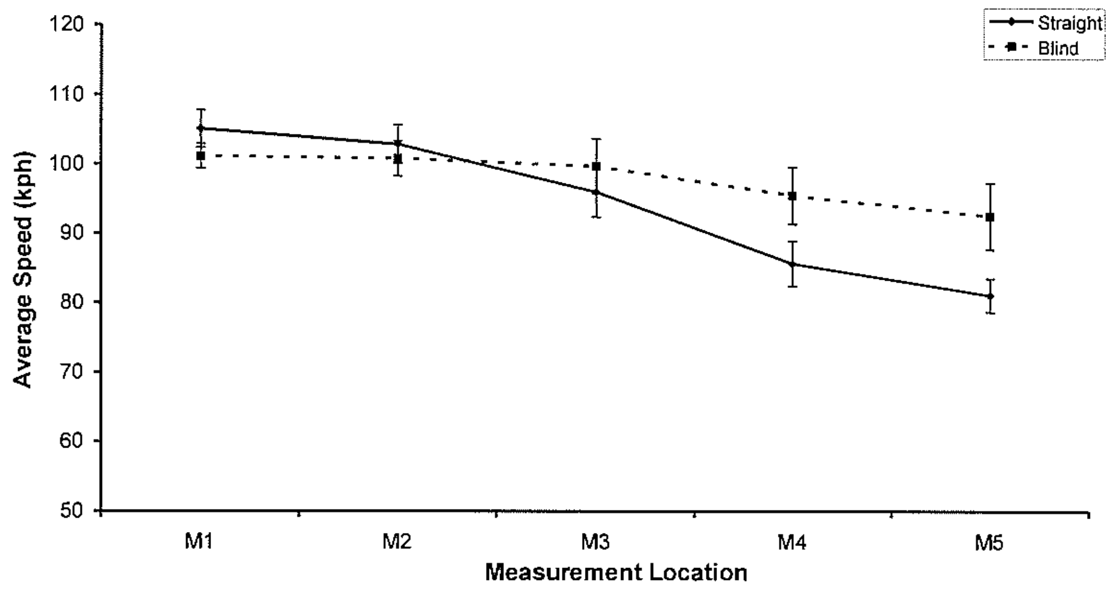


Figure 5.7 Average speed across straight and blind merges.

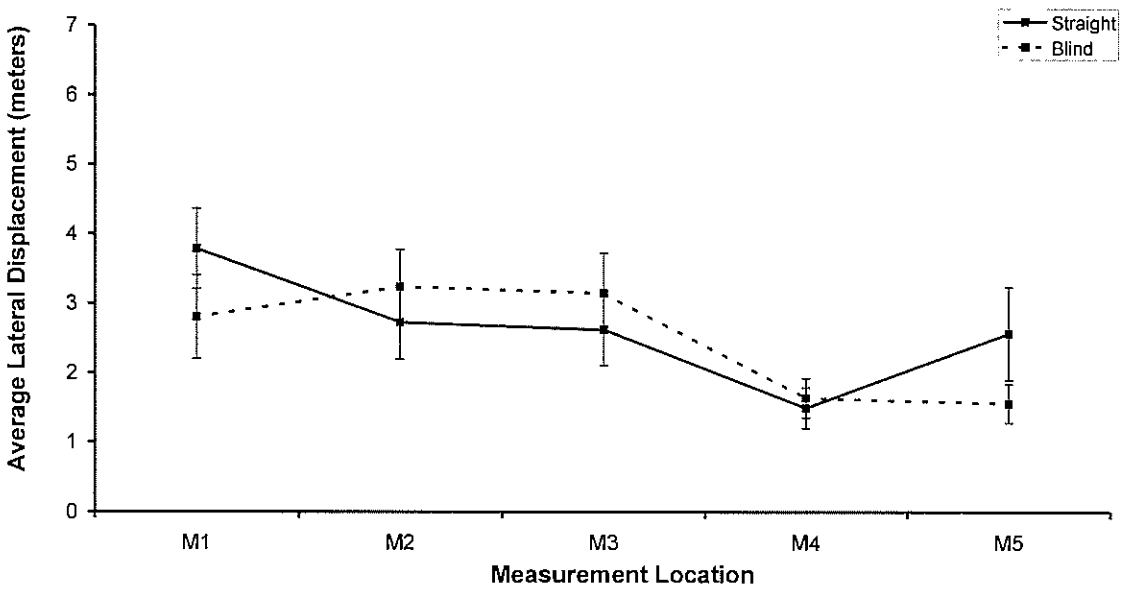


Figure 5.8 Average lateral displacement across straight and blind merges.

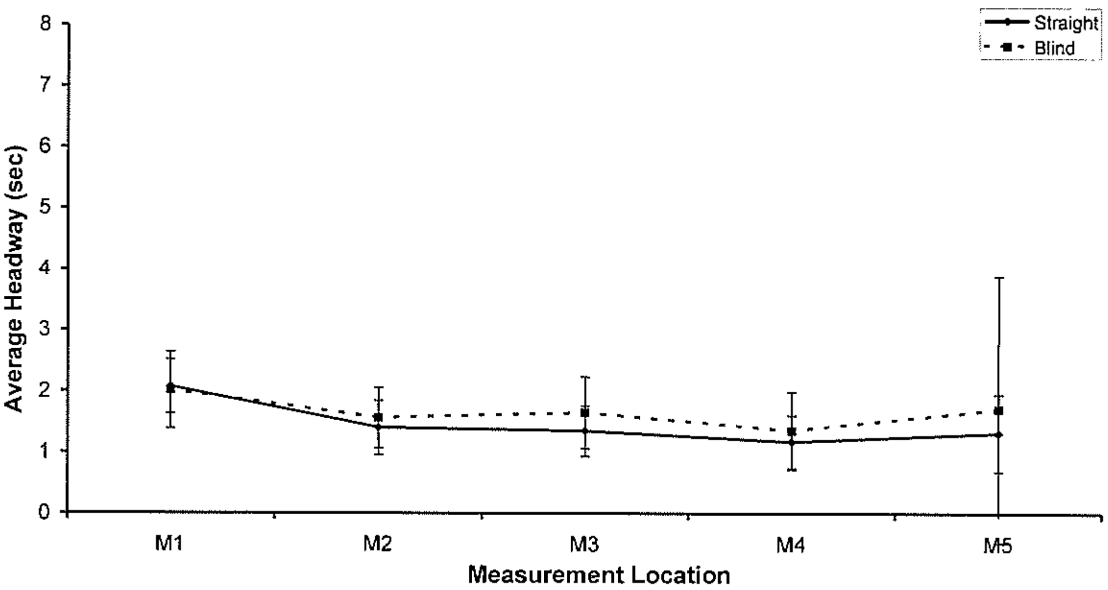


Figure 5.9 Headway across straight and blind merges.

In addition, lateral displacement data also showed a significant treatment x position interaction ($F(4,27) = 4.817$, $p < 0.01$). Figure 5.8 shows that drivers were further to the left at both M1 and M5 at the straight merge, and at all other measurement locations the lateral displacements across both conditions showed similar values.

No corresponding treatment x position interaction was noted for headway ($F(4,27) = 0.313$, $p > 0.10$) (Figure 5.9). Descriptive statistics for these comparisons are provided in Appendix J.

Participant Ratings

It was also of interest to examine participant ratings and comments regarding these two lane designs. Participants were asked to rate the clarity (for required driver behaviour), effectiveness, and safety of the passing lane designs on a scale of one to ten: with 1 being very unclear/ ineffective/ unsafe to 10 being very clear/ effective/ safe. Table 5.3 outlines the mean ratings for each scale, and it shows that participants rated the straight merge as marginally clearer and more effective but no safer than the blind merge.

Table 5.3 Participant ratings for merge treatments.

Merge Treatment	Blind		Straight	
Rating	**Mean**	**SD**	**Mean**	**SD**
Clarity	5.0	2.1	5.6	2.3
Effectiveness	4.7	2.0	5.2	2.0
Safety	5.1	1.9	5.1	2.2

Participants made few comments about these designs, probably because they were already relatively familiar with them. Comments that were made included:

- *"Why merge on bends?"*
- *"I would like to see as many passing lanes as possible end well before a blind corner so that all vehicles are back in single file at the corner."*

5.2.3 Effect of Taper Length

The next question concerned the impact of taper length on driver behaviour. Taper lengths that are typically present on New Zealand roads were compared to taper lengths that meet the Austroads standards. Where long taper is used in this research it is equivalent to the Austroads standard. Figures 5.10, 5.11, and 5.12 provide comparisons of driver speed, lateral displacement, and headways for the sites with different taper lengths. Oblique and plan views of the simulations for short taper and standard taper are presented in Figures 5.13 and 5.14 respectively.

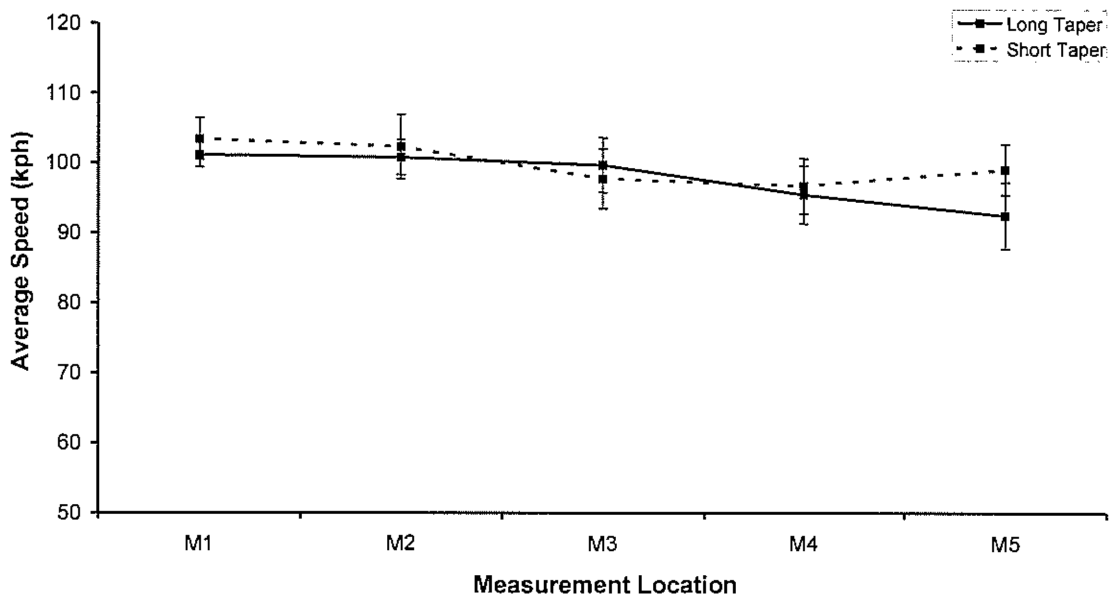


Figure 5.10 Average speeds across short tapers, compared with Austroads standard (or long) tapers.

A repeated-measures MANOVA showed a significant treatment x position interaction for this comparison ($F(4,27) = 4.302$, $p < 0.01$). Statistical analysis indicated that this was due primarily to the treatment x position effect on participants' speed ($F(4,27) = 3.585$, $p < 0.05$).

An examination of Figure 5.10 shows that drivers in the short taper situation exhibit higher speeds at the end of the merge area, with speeds maintained from M3 to M4 and increasing from M4 to M5 under this condition. The long taper condition shows a steady reduction in speeds between locations M1 and M5 of 8.7 kph. A significant effect of lateral displacement was also shown ($F(4,27) = 3.430$, $p < 0.05$). Figure 5.11 shows that drivers were positioned further to the left, away from the centreline, at M4 in the short taper condition.

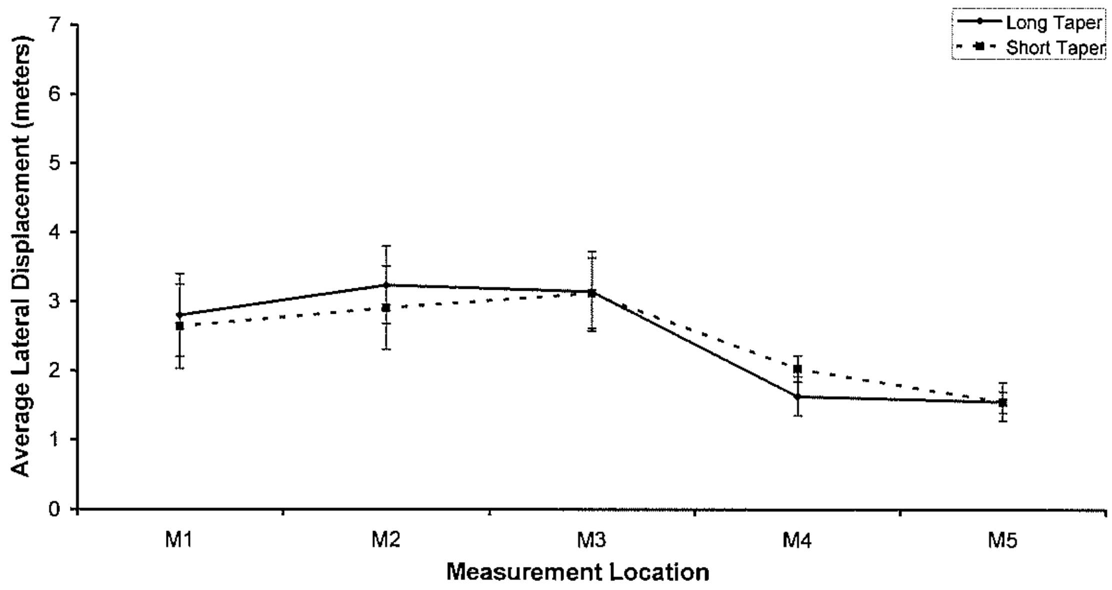


Figure 5.11 Average lateral displacement compared with short tapers and Austroads standard (or long) tapers.

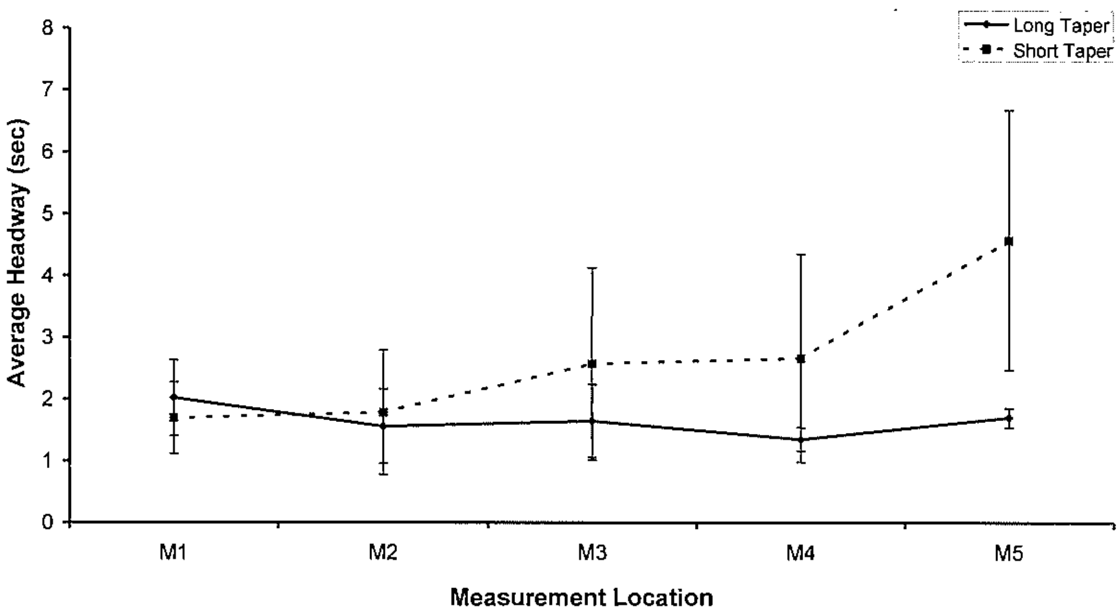


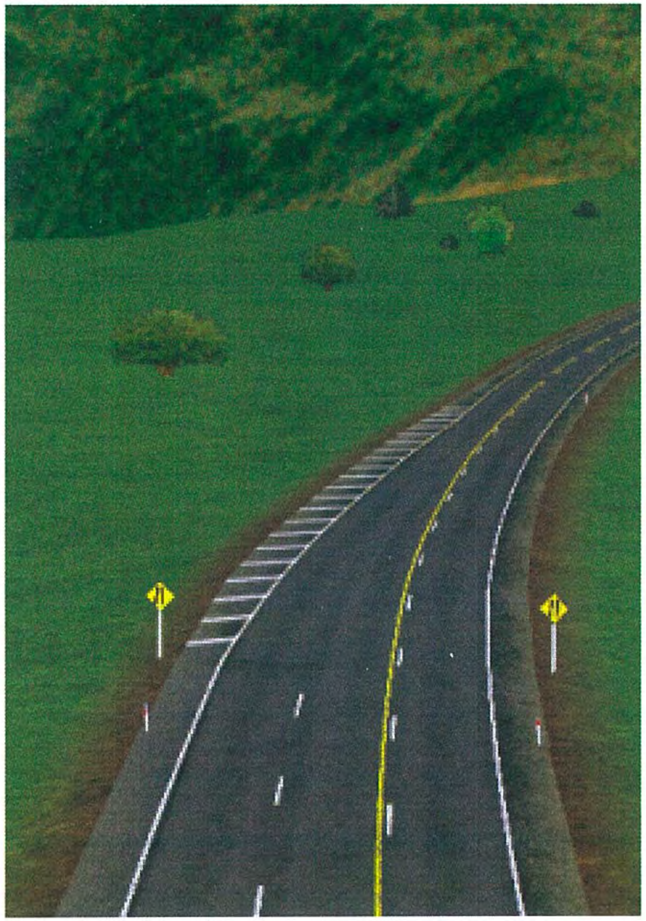
Figure 5.12 Average headway across short tapers and Austroads standard (or long) tapers.

The variability of the headway data resulted in only a marginally significant treatment effect ($F(1,30) = 3.880$, $p < 0.058$). Descriptive statistics for these comparisons are shown in Appendix J.

Participant Ratings

In addition, participants were asked to rate the clarity, effectiveness, and safety of the passing lanes. Table 5.4 provides an overview of these participant ratings, and it shows that participants generally preferred the long merge taper.

Figure 5.13 Oblique scan (left) and screen shot of plan view (right) of the simulated short taper merge design.



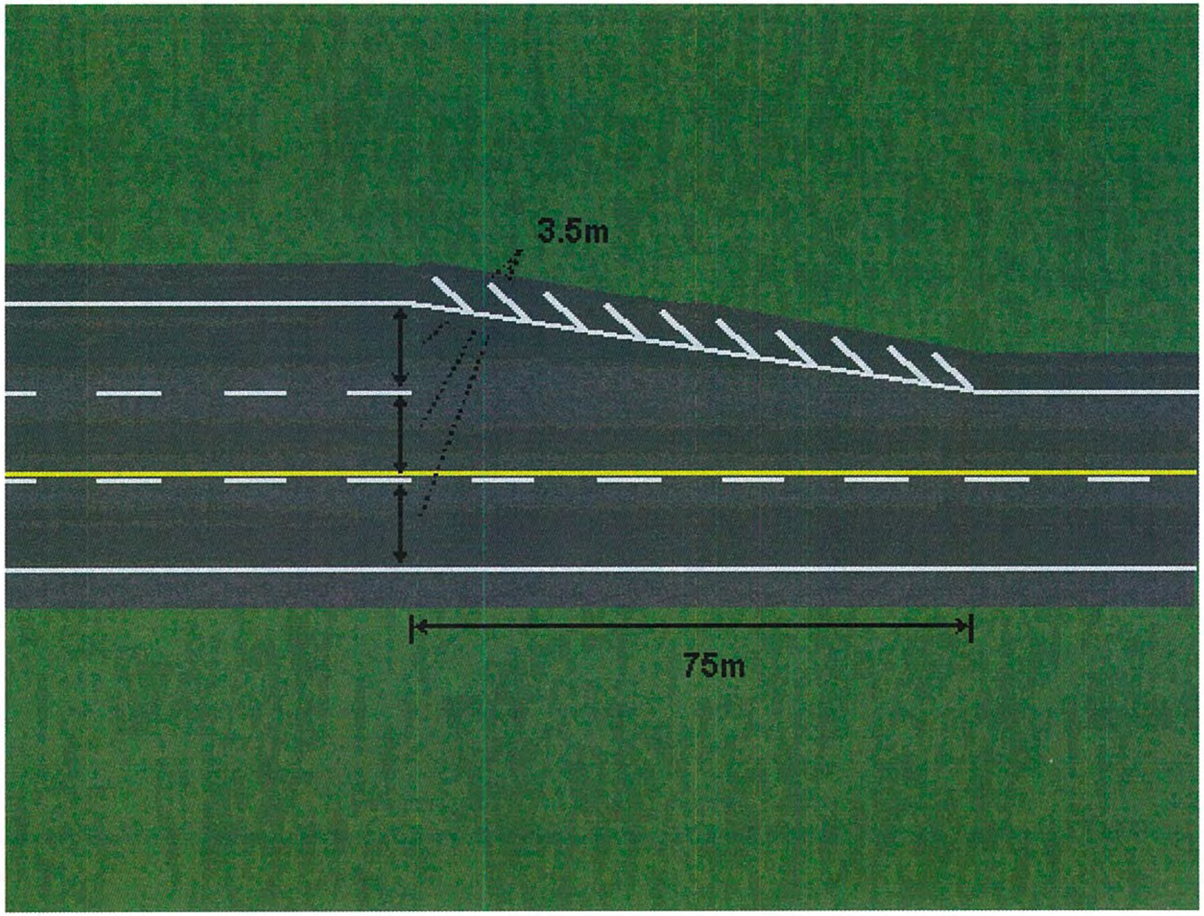
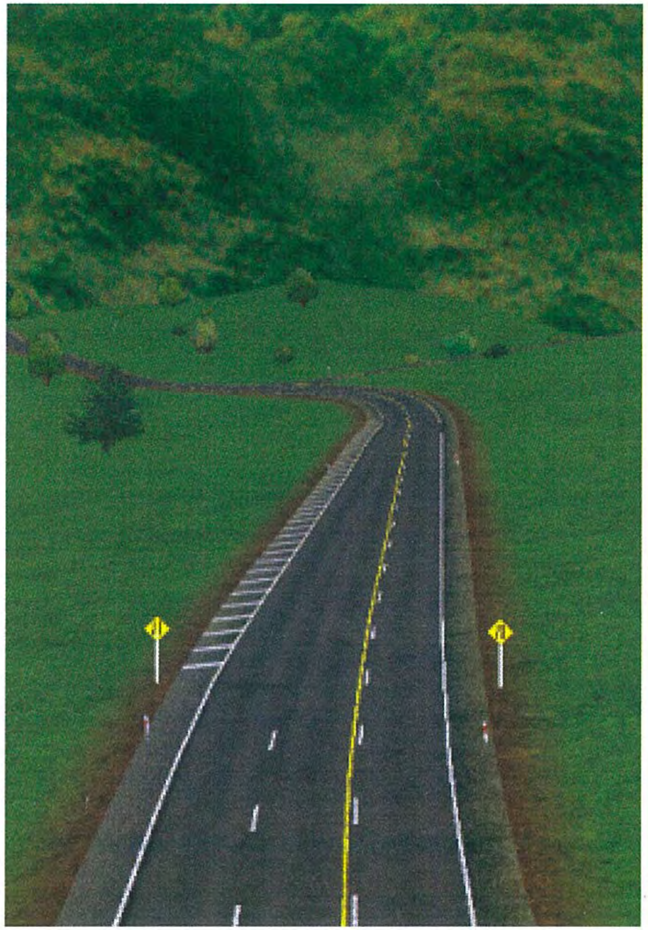


Figure 5.14 Oblique scan (left) and screen shot of plan view (right) of the simulated standard taper merge design.



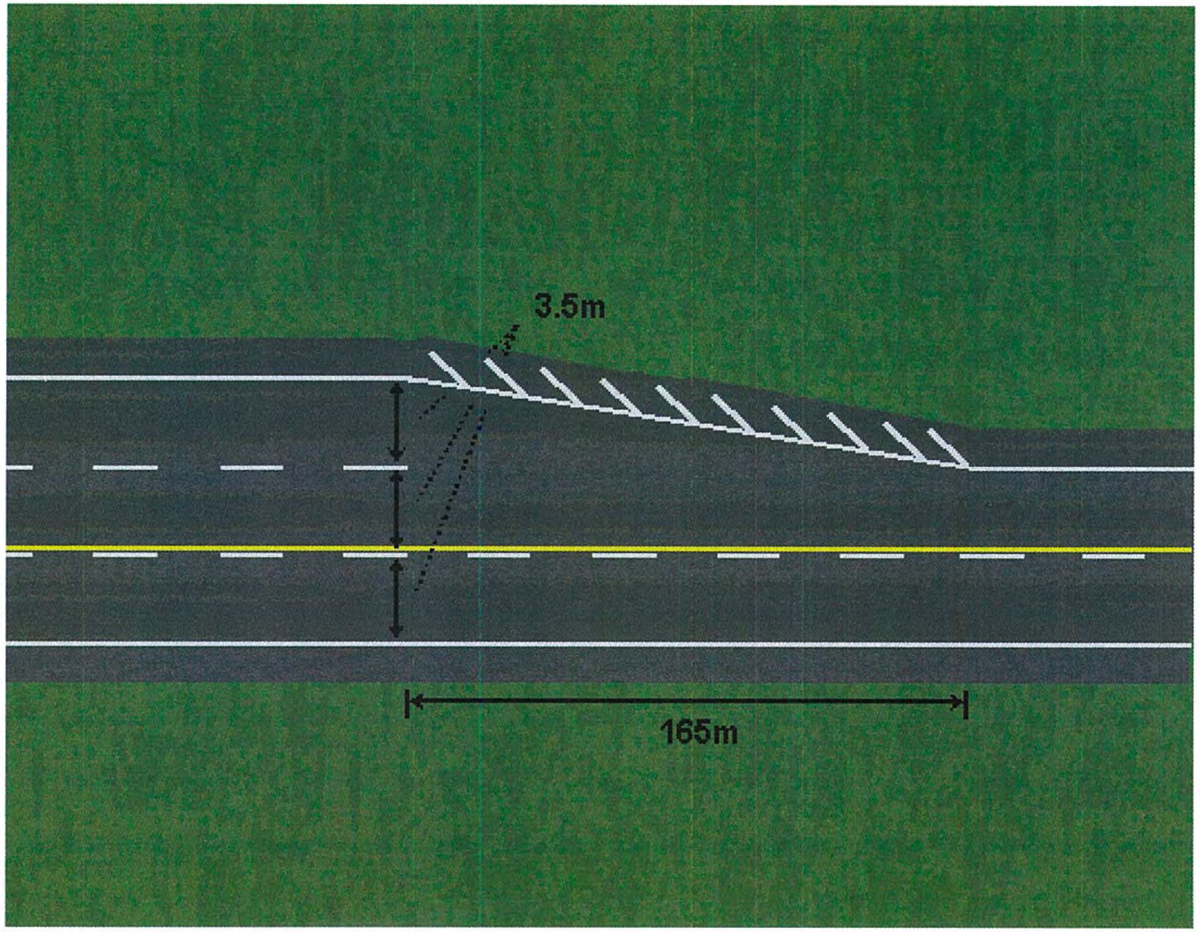


Table 5.4 Participant ratings for taper length treatments.

Taper Length Treatment	Short		Long	
Rating	Mean	SD	Mean	SD
Clarity	4.1	1.9	4.8	2.0
Effectiveness	4.1	1.9	4.7	2.0
Safety	4.2	1.9	5.1	1.9

Comments were made by several participants about the taper length issue, some of which included:

- *"Longer merge is better."*
- *"Short merge on blind bend is too dangerous."*
- *"Longer distances for merging were better."*

5.2.4 Effect of Early Lane Line Termination

One of the key questions regarding the effect of merge design on driver behaviour was how the early termination of the lane line (between the two passing lanes) would affect merging behaviour. The following analyses sought to answer this question and, as shown in Figures 5.15, 5.16, and 5.17, provide an overview of the effect of early termination of the lane line compared to the standard or early termination marking currently on the road. Figure 5.18 shows oblique scan and screen shot of plan views of the simulated early lane line termination.

The standard position of the lane line termination is where the markings end at the beginning of the merge taper. For the early termination situation, the lane line markings end 55 m before the taper begins.

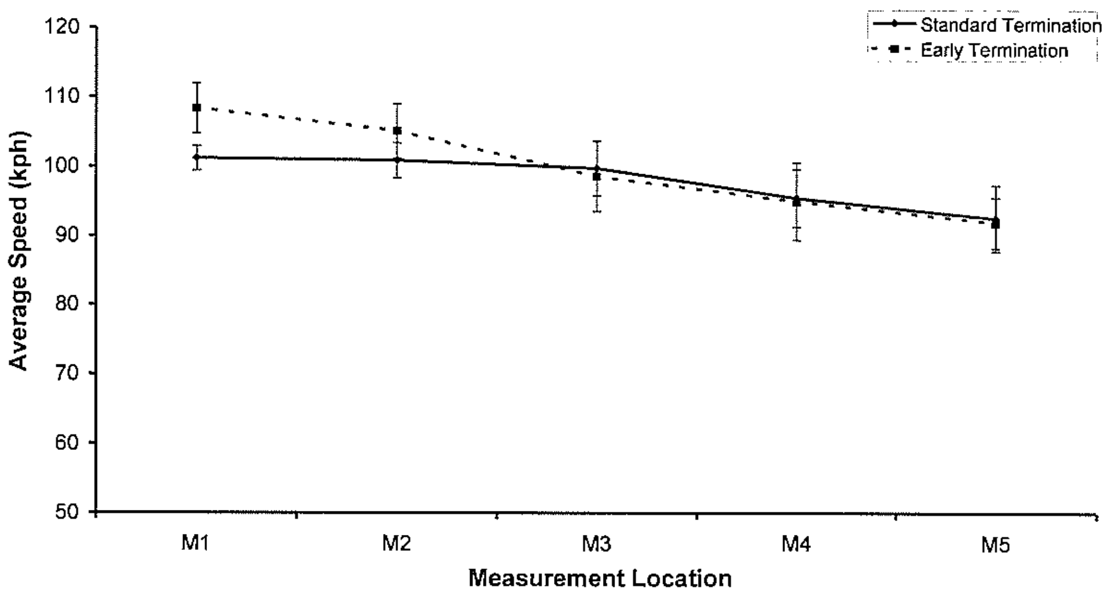


Figure 5.15 Average speeds across early lane line termination and standard lane line termination.

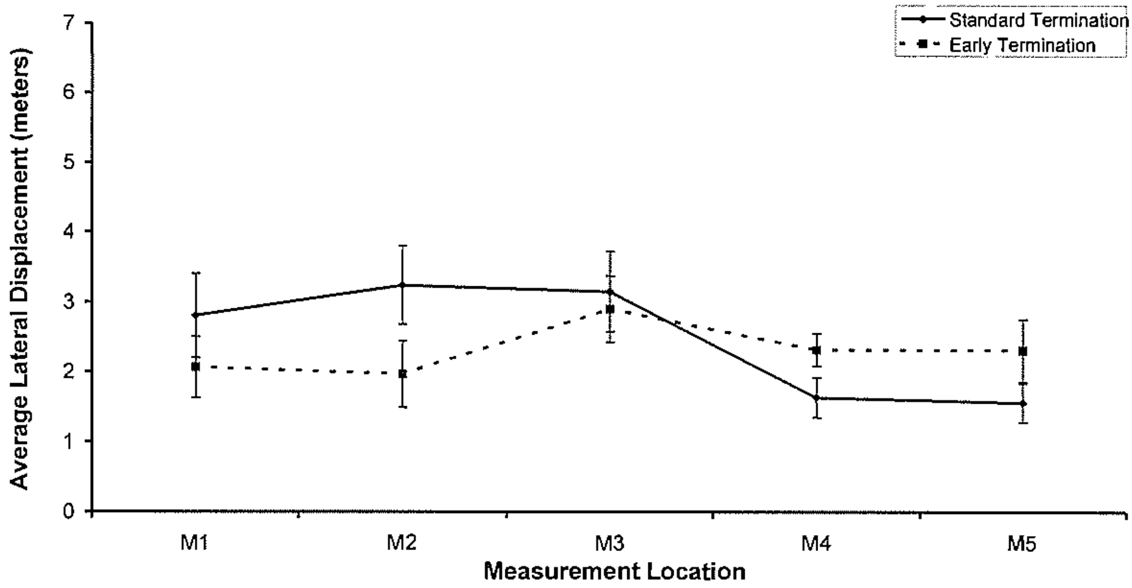


Figure 5.16 Average lateral displacement across early lane line termination and standard lane line termination.

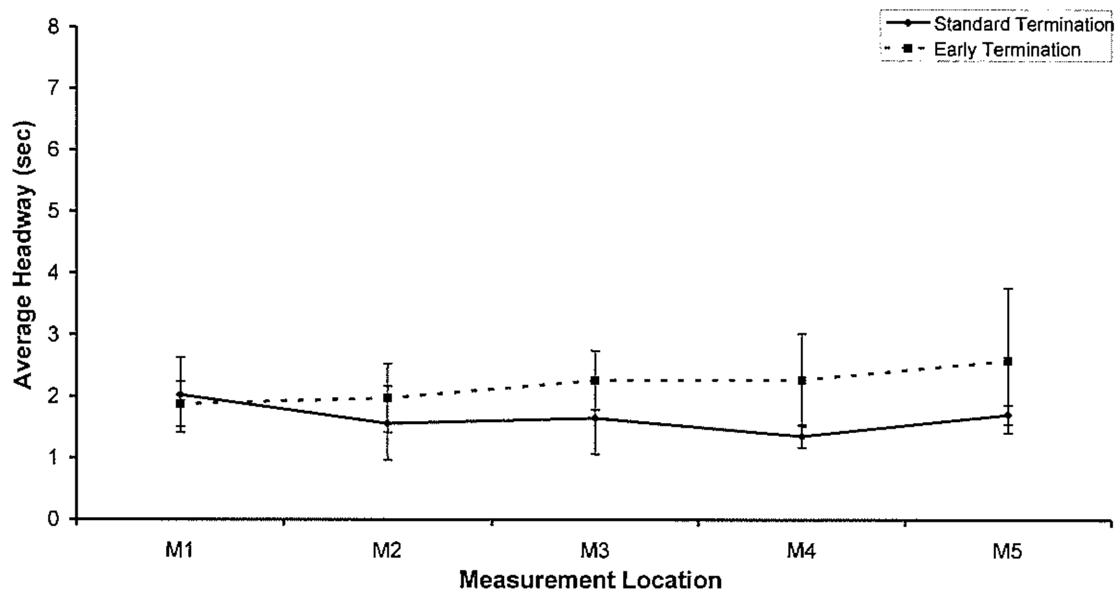
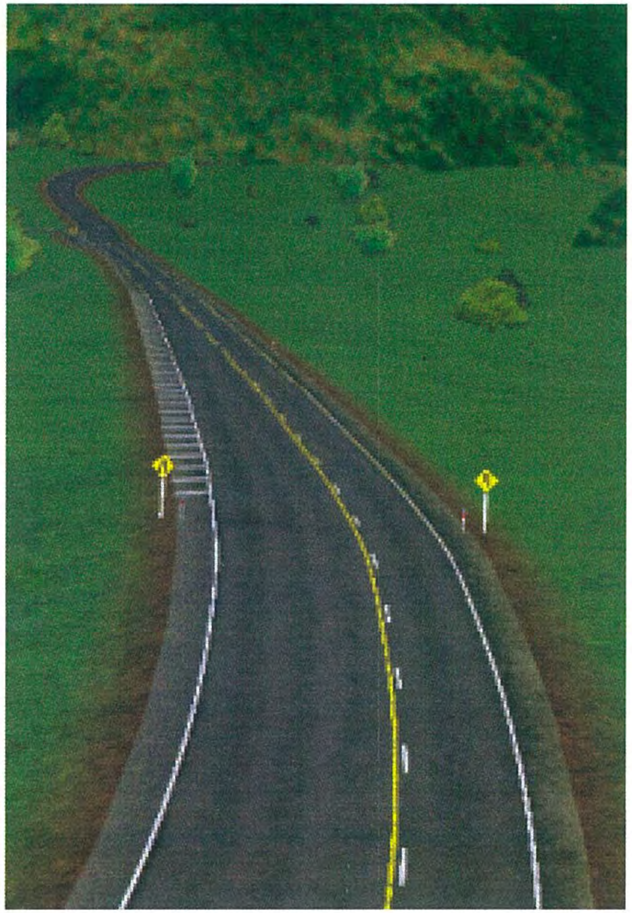
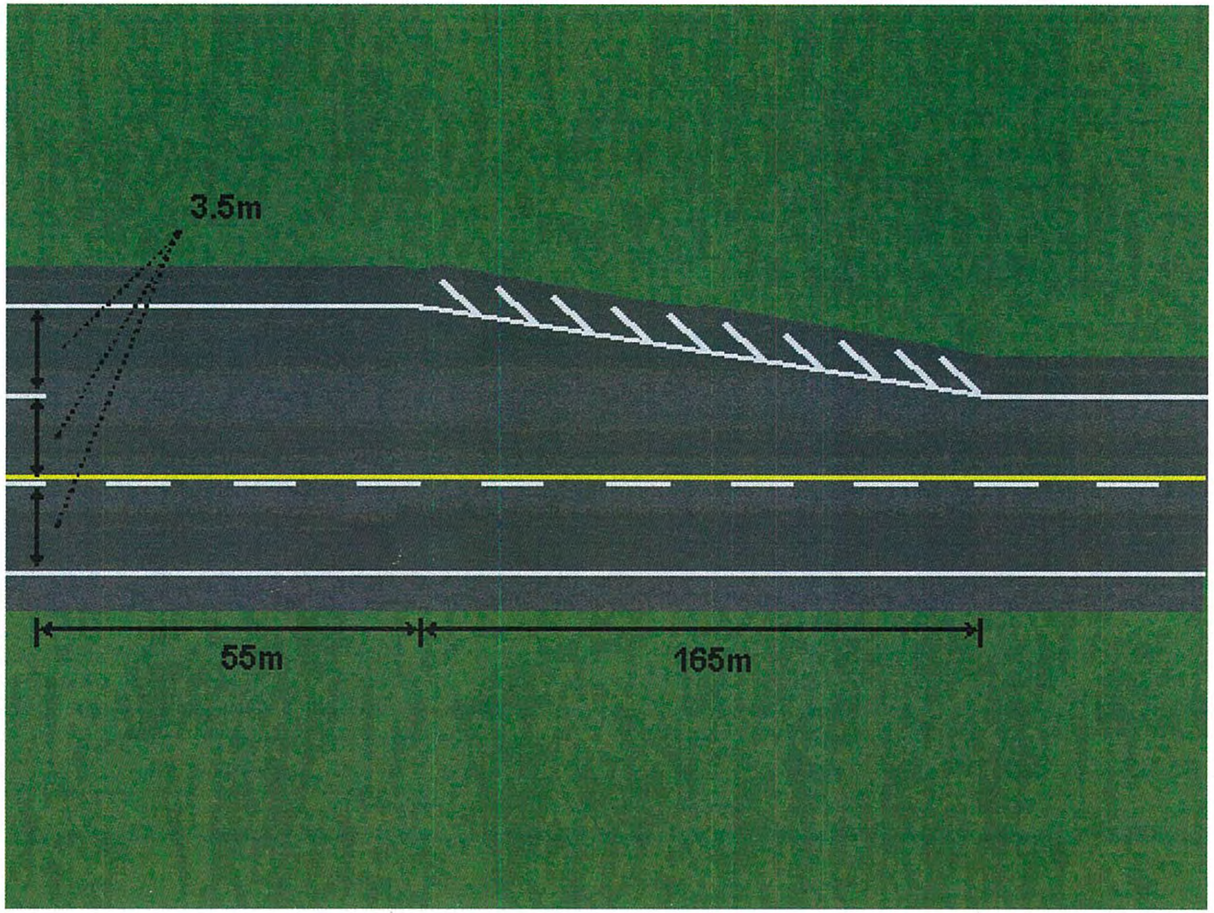


Figure 5.17 Average headway across early lane line termination and standard lane line termination.

Figure 5.18 Oblique scan (left) and screen shot of plan view (right) of the simulated early lane line termination merge design.





A repeated-measures MANOVA indicated a significant treatment x position x measure interaction for this comparison ($F(8,23) = 3.737$, $p < 0.01$). This was primarily because the treatment x position had an effect on participants' speed ($F(4,27) = 3.514$, $p < 0.05$) and lateral displacement ($F(4,27) = 7.786$, $p < 0.001$).

An examination of Figure 5.15 shows marked differences in speed between the two conditions at locations M1 and M2, but that by M3 the speeds are almost identical and remain so through locations M4 and M5. A particularly notable drop in mean speeds (6.5 kph) occurs between locations M2 and M3 for the early termination treatment. It is possible that this is related to the early termination treatment (which occurs between M2 and M3), but because of the disparity in speeds between conditions at locations M1 and M2, this result should be interpreted with some caution.

The lateral displacement data (Figure 5.16) shows that in the standard termination treatment the drivers were, on average, further to the left as they approached the merge area (M1 and M2). Between locations M2 and M3, the drivers in the early termination treatment exhibited a marked shift to the left, so that their position essentially matched that of the drivers in the standard termination condition. Once again, this is possibly a result of the early termination of the lane line, however this effect may reflect differences in behaviour between the two conditions at locations M1 and M2.

The variability of the headway data (Figure 5.17) resulted in non-significant statistics for the main and interaction effects ($F(1,30) = 2.223$, $p > 0.10$, $F(4,27) = 1.274$, $p > 0.10$). Descriptive statistics for these comparisons are shown in Appendix J.

Participant Ratings

Participants were again asked to rate the clarity, effectiveness, and safety of the passing lanes. As Table 5.5 shows, participants clearly preferred the on-road standard to an early termination of the lane line.

Table 5.5 Participant ratings for early lane line termination treatments.

Lane Line Treatment	Early Lane Line		Standard Lane Line	
Rating	**Mean**	**SD**	**Mean**	**SD**
Clarity	3.9	2.1	5.0	2.1
Effectiveness	3.6	2.2	4.8	2.0
Safety	3.4	2.2	5.1	1.9

Participant comments included:

- *"Centre [lane] line disappearing could be dangerous."*
- *"Middle [lane] line finished too early."*
- *"Simply removing the centre [lane] line wasn't effective at all."*
- *"Motorists will still try to pass in the wider bit of the end of the lane markings, this passing would be on a bend, possibly at speed."*

5.2.5 Effect of Double Herringbone Treatment with Long Taper

The fourth key question about merge design was how paint treatments would impact on driver merging behaviour. Figures 5.19, 5.20, and 5.21 compare driver behaviour at a standard long merge taper with the same long merge taper design having the addition of a double herringbone treatment. The oblique scan and screen shot of plan view of this treatment are shown in Figure 5.22.

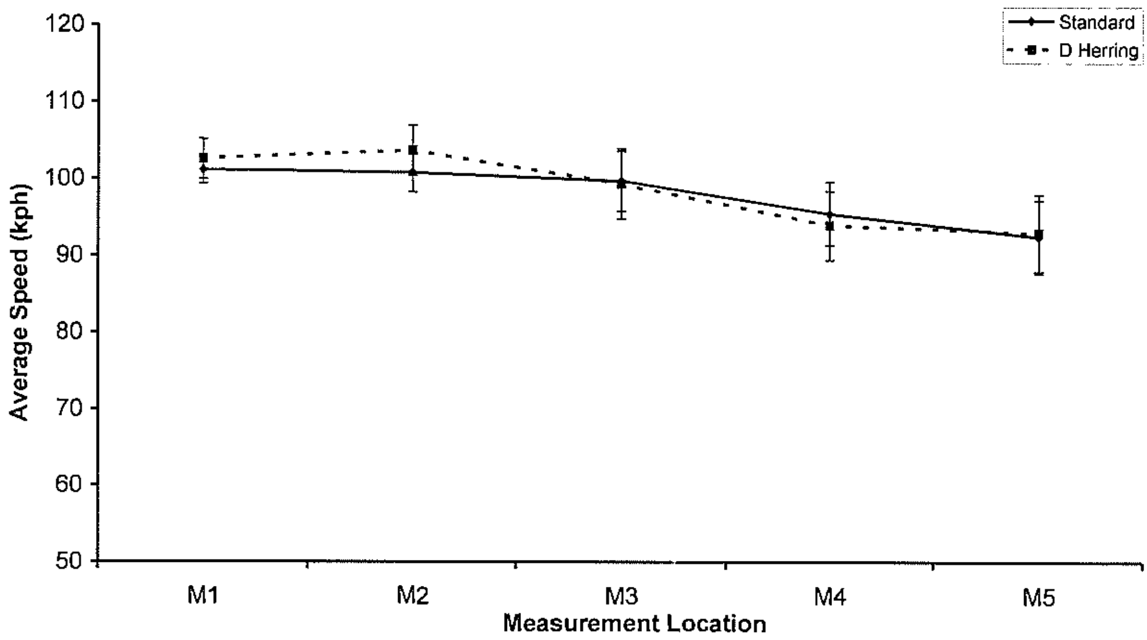


Figure 5.19 Average speeds across double herringbone treatment and standard treatment, both on long tapers.

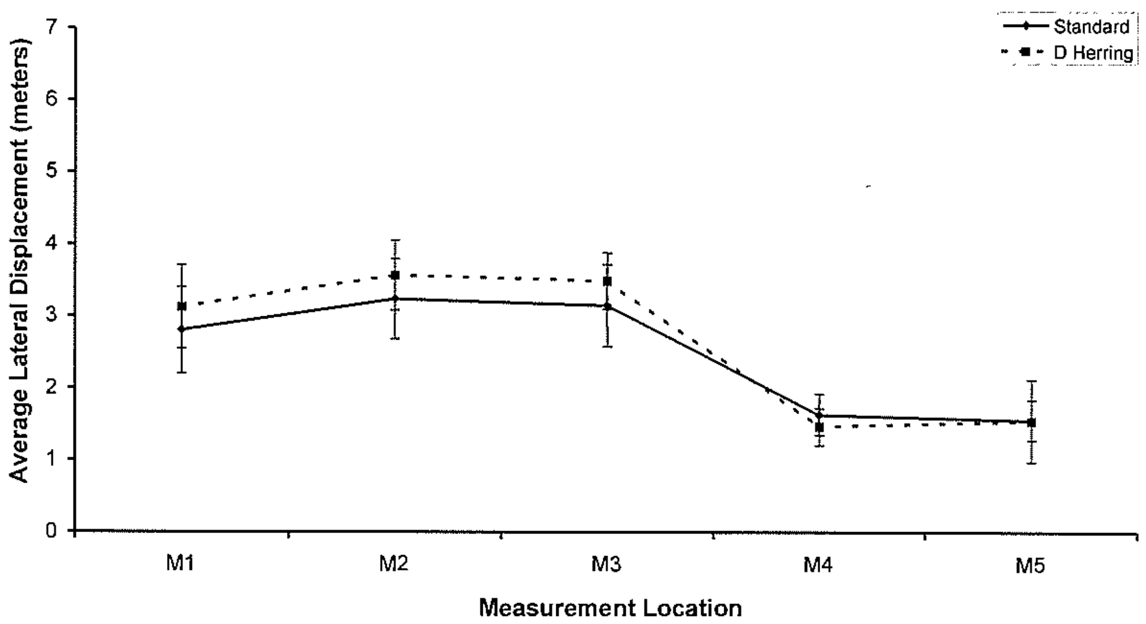


Figure 5.20 Average lateral displacement across double herringbone treatment and standard treatment, both on long tapers.

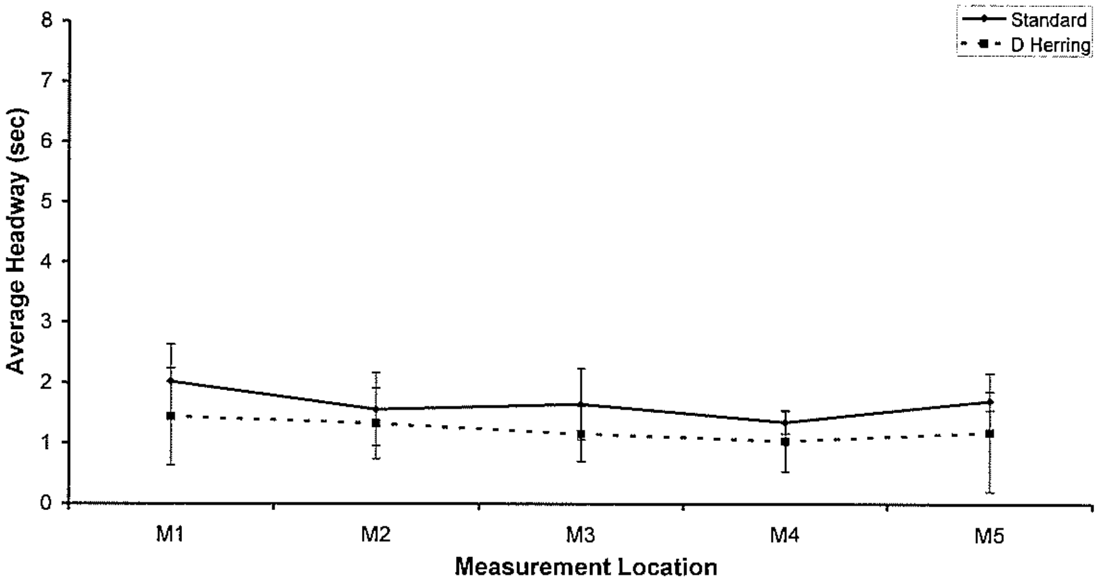


Figure 5.21 Average headway across double herringbone treatment and standard treatment, both on long tapers.

A repeated-measures MANOVA did not indicate any treatment x position x measure interaction ($F(8,23) = 1.062$, $p > 0.10$), or main effect of treatment ($F(1,30) = 0.025$, $p > 0.10$) for the double herringbone paint treatment. This indicates that the treatment had no significant effect on driver behaviour. Descriptive statistics for this comparison are shown in Appendix J.

Participant Ratings

Participant ratings outlined in Table 5.6 show that, despite the treatment having little effect on driver behaviour, it was generally well received because it provided a very clear indication that the merge was approaching.

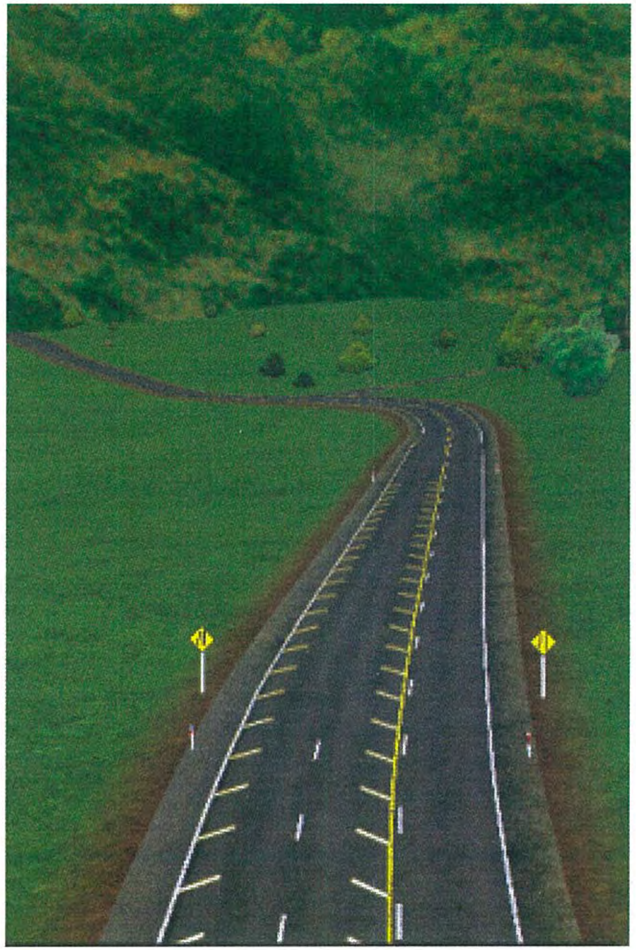
Table 5.6 Participant ratings for double herringbone and standard treatments, on long tapers.

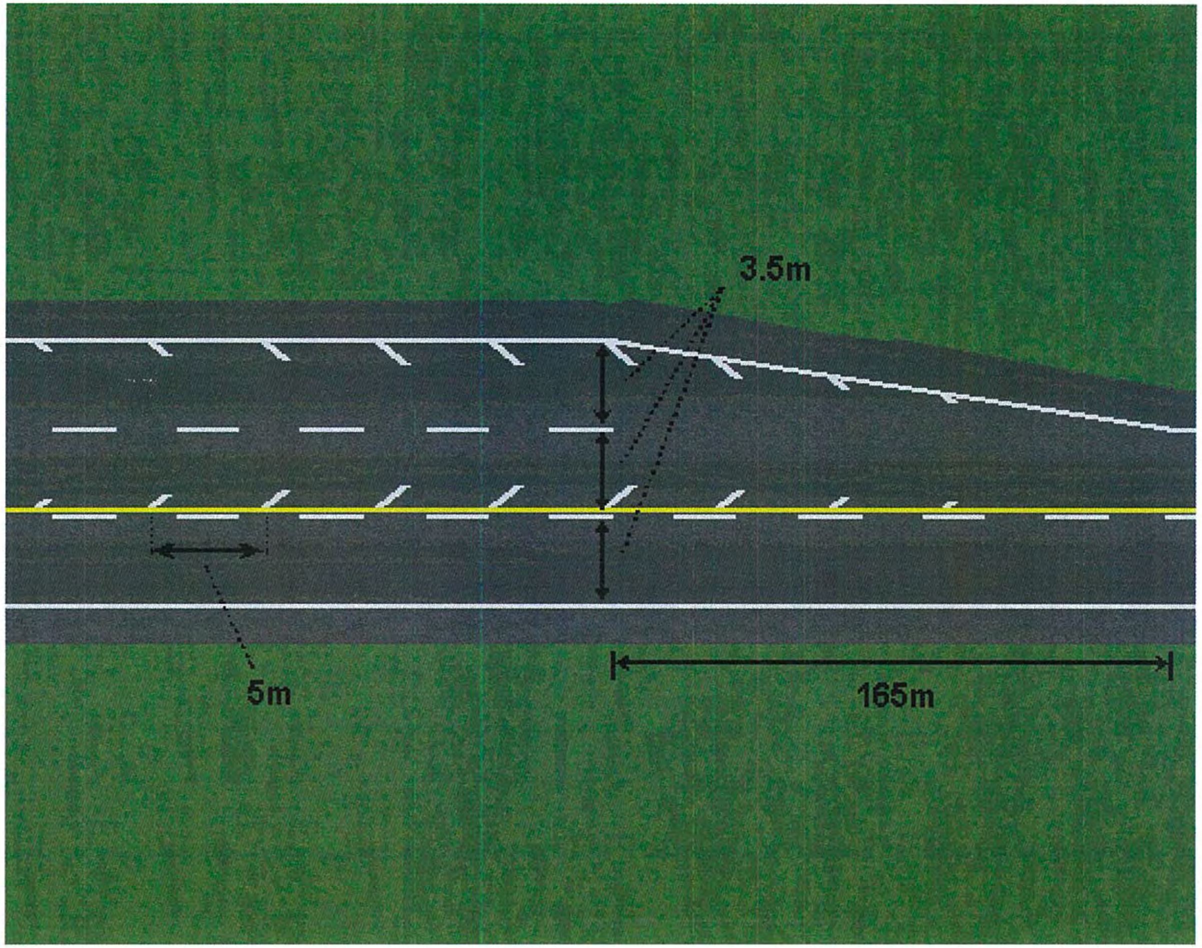
Paint Treatment	Double Herringbone		Standard	
Rating	Mean	SD	Mean	SD
Clarity	7.5	2.4	5.0	2.1
Effectiveness	7.5	2.2	4.8	2.0
Safety	7.2	2.5	5.1	1.9

Participants' comments included:

- *"I feel it [the herringbone?] is pushing you too much. It would make cars go closer together which is dangerous. It is hard enough concentrating without having to avoid driving on lines."*
- *"This was a little confusing at first and I found myself drifting into the middle of the road."*
- *"This was my favourite, encouraged a safe merge and longer distance made merging more intuitive."*
- *"I think this design is the best, the double herringbone works effectively and both cars on either side are made aware of the merge."*

Figure 5.22 Oblique scan (left) and screen shot of plan view (right) of the simulated double herringbone with long taper merge design.





5.2.6 Effect of Double Herringbone Treatment with Short Taper

The next analysis examined the impact of the double herringbone paint treatment on a short merge taper by comparing a standard short merge taper to the same treatment with the addition of a double herringbone. Figures 5.23, 5.24 and 5.25 show little difference between driver behaviour on the short taper merges with and without the herringbone treatment. The plan and oblique views of this treatment are shown in Figure 5.26.

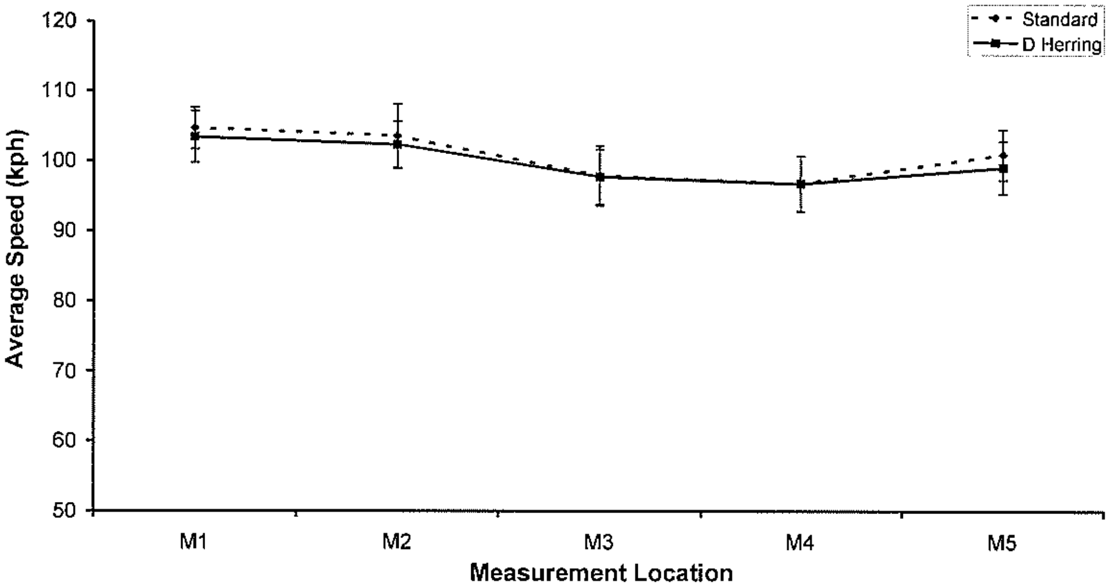


Figure 5.23 Average speeds across double herringbone treatment and standard treatment, both on short tapers.

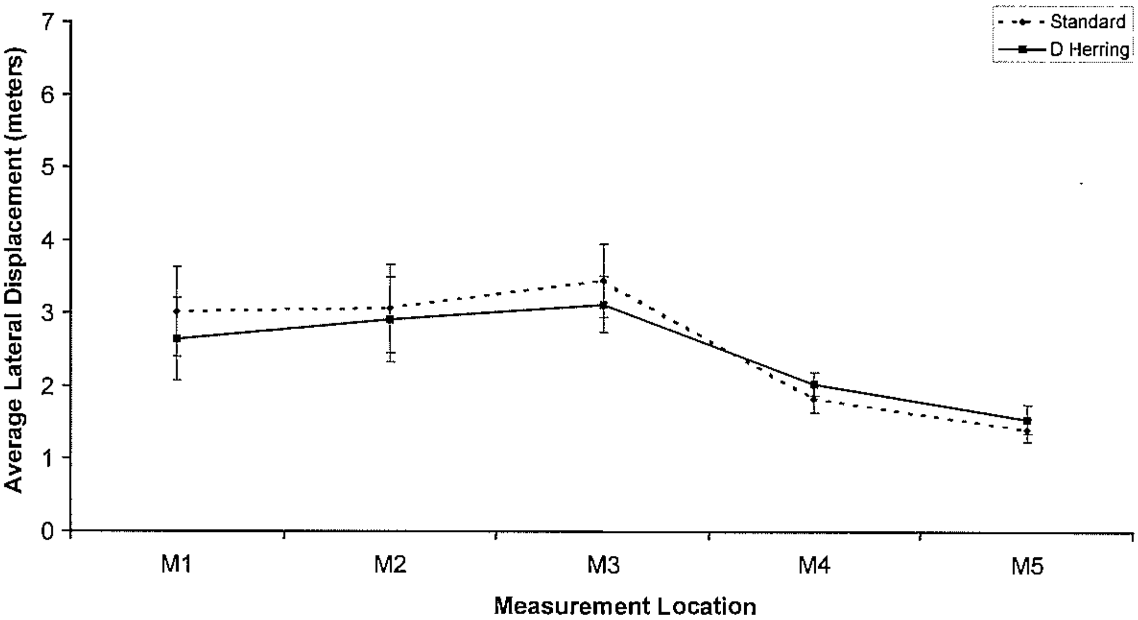


Figure 5.24 Average lateral displacement across double herringbone treatment and standard treatment, both on short tapers.

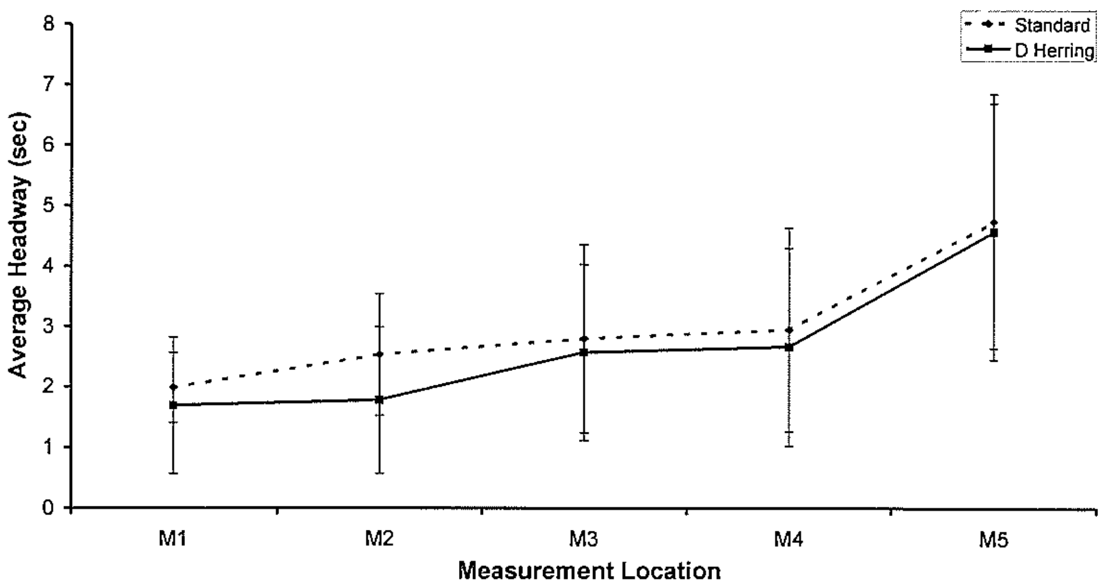


Figure 5.25 Average headway across double herringbone treatment and standard treatment, both on short tapers.

A repeated-measures MANOVA found no treatment x position x measure interaction ($F(8,23) = 1.386$, $p > 0.10$) or main effect of treatment ($F(1,30) = 0.466$, $p > 0.10$) for the herringbone paint treatment. Descriptive statistics for this comparison are shown in Appendix J.

Participant Ratings

Participant ratings are outlined in Table 5.7. As with the previous double herringbone comparison, most participants clearly preferred this to the standard treatment despite the fact that it had no significant effect on their behaviour.

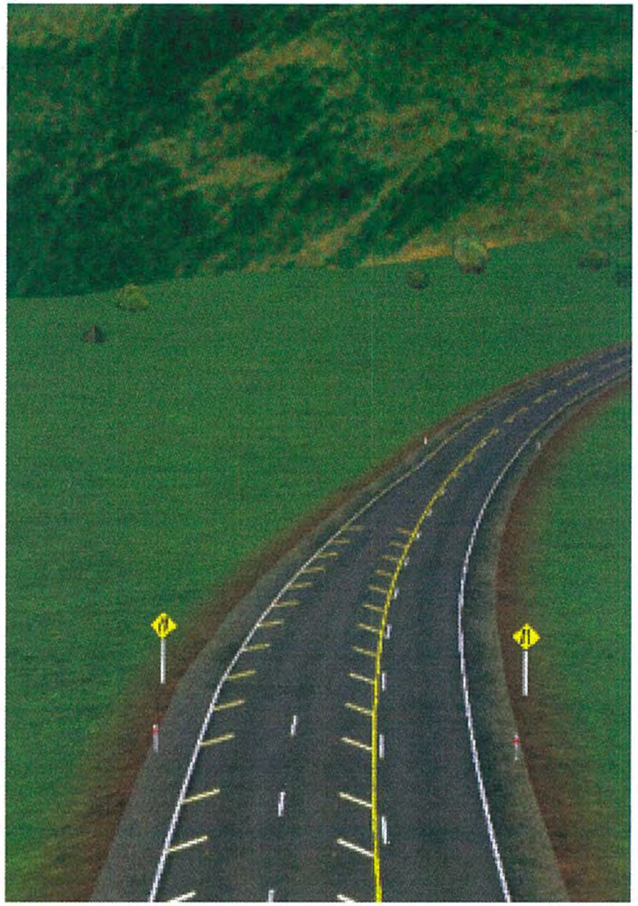
Table 5.7 Participant ratings for double herringbone and standard treatments, on short tapers.

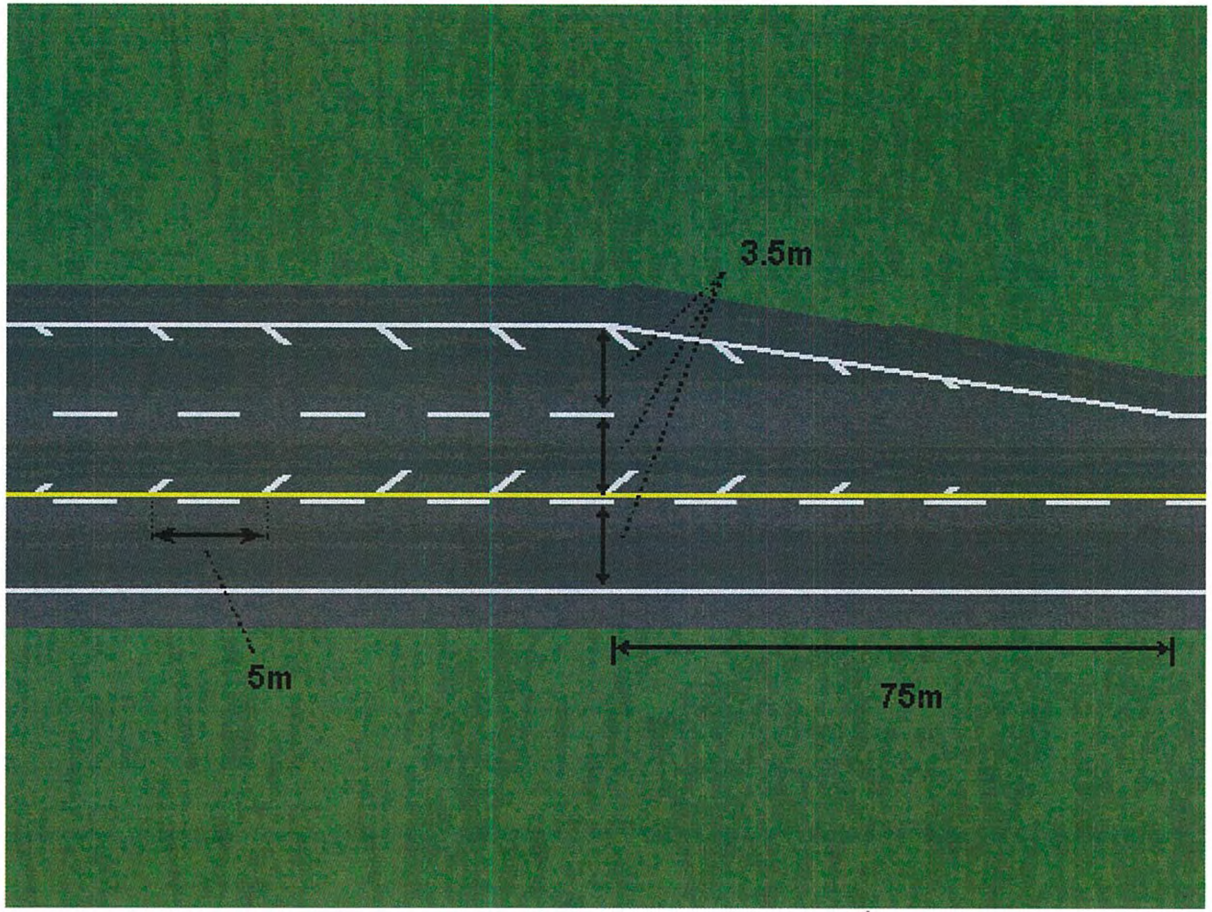
Paint Treatment	Double Herringbone		Standard	
Rating	**Mean**	**SD**	**Mean**	**SD**
Clarity	6.9	2.4	4.6	1.9
Effectiveness	6.5	2.2	4.1	1.9
Safety	6.0	2.0	4.1	1.9

Participants' comments included:

- *"More dangerous as pushing both left and right lanes together, not just the right."*
- *"Great clear design, distance seemed somewhat short."*
- *"It was hard to see what was happening, also people were still passing at this point."*

Figure 5.26 Oblique screen shot (left) and plan view (right) of the simulated double herringbone with short taper merge design.





5.2.7 Effect of Right Herringbone Treatment with Short Taper

The last analysis carried out was of the right herringbone treatment[10] on short taper merges. Figures 5.27, 5.28 and 5.29 provide comparisons of average speed, lateral displacement, and headways. Figure 5.30 shows plan and oblique views of this treatment.

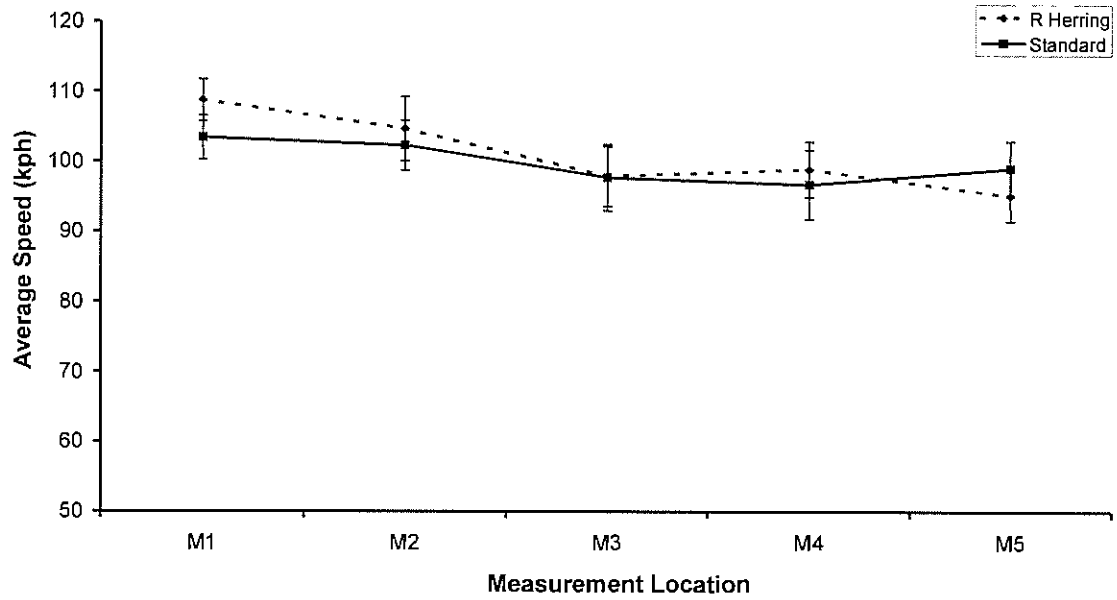


Figure 5.27 Average speeds across right herringbone treatment and standard treatment, both on short tapers.

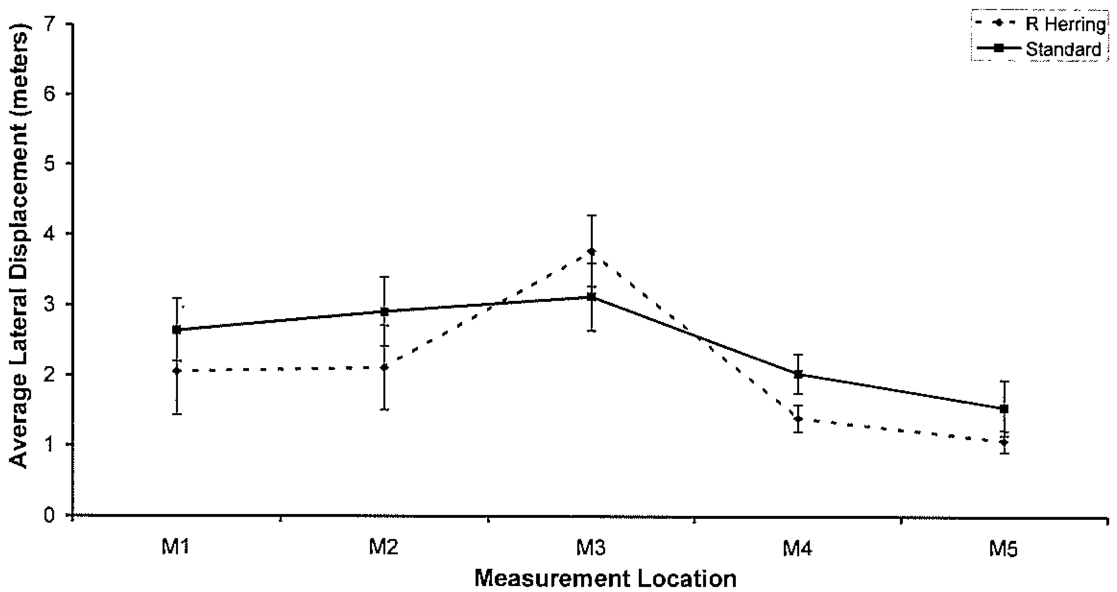


Figure 5.28 Average lateral displacement across right herringbone treatment and standard treatment, both on short tapers.

[10] A right herringbone is placed on the right side of the passing lane adjacent to the road centreline.

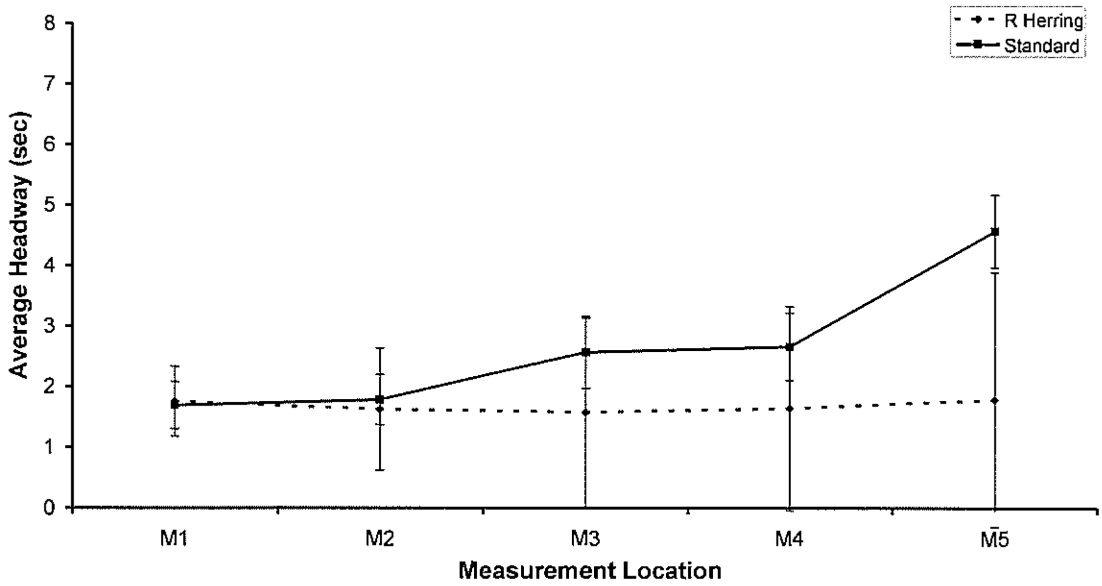


Figure 5.29 Average headway across right herringbone treatment and standard treatment, both on short tapers.

A repeated-measures MANOVA showed a significant treatment x position x measure interaction for this comparison ($F(8,23) = 6.449$, $p < 0.001$).

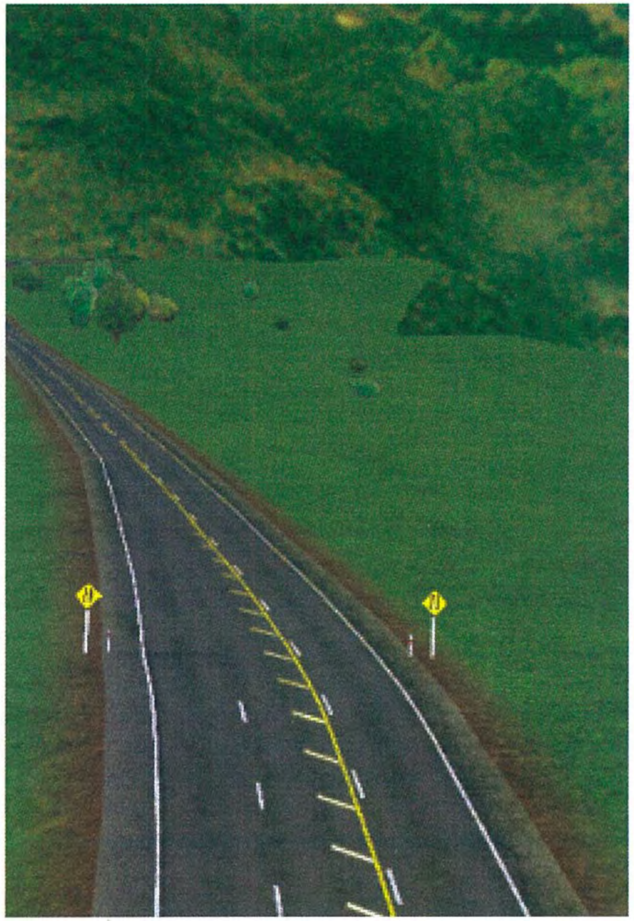
Statistical analysis indicated that this was due to consistent treatment x position effects on participants' speed ($F(4,27) = 5.226$, $p < 0.01$), lateral displacement ($F(4,27) = 3.554$, $p < 0.05$), and headway ($F(4,27) = 7.307$, $p < 0.001$). An examination of Figures 5.27, 5.28 and 5.29 shows that the most notable difference in the speed profiles occurs at M1, and, as such, cannot be attributed to anything to do with the design of the merge area. Lateral displacement (Figure 5.28) shows a distinct move to the left for those drivers in the right herringbone condition between locations M2 and M3. This is likely to be a result of the right herringbone treatment, with the treatment encouraging drivers to move to the left. However due to the disparity in lateral displacements between the two treatments at locations M1 and M2, this result should be interpreted with some caution. It is also apparent that in the right herringbone treatment, drivers maintained consistently closer following distances (headways), well within the danger threshold of 2 seconds.

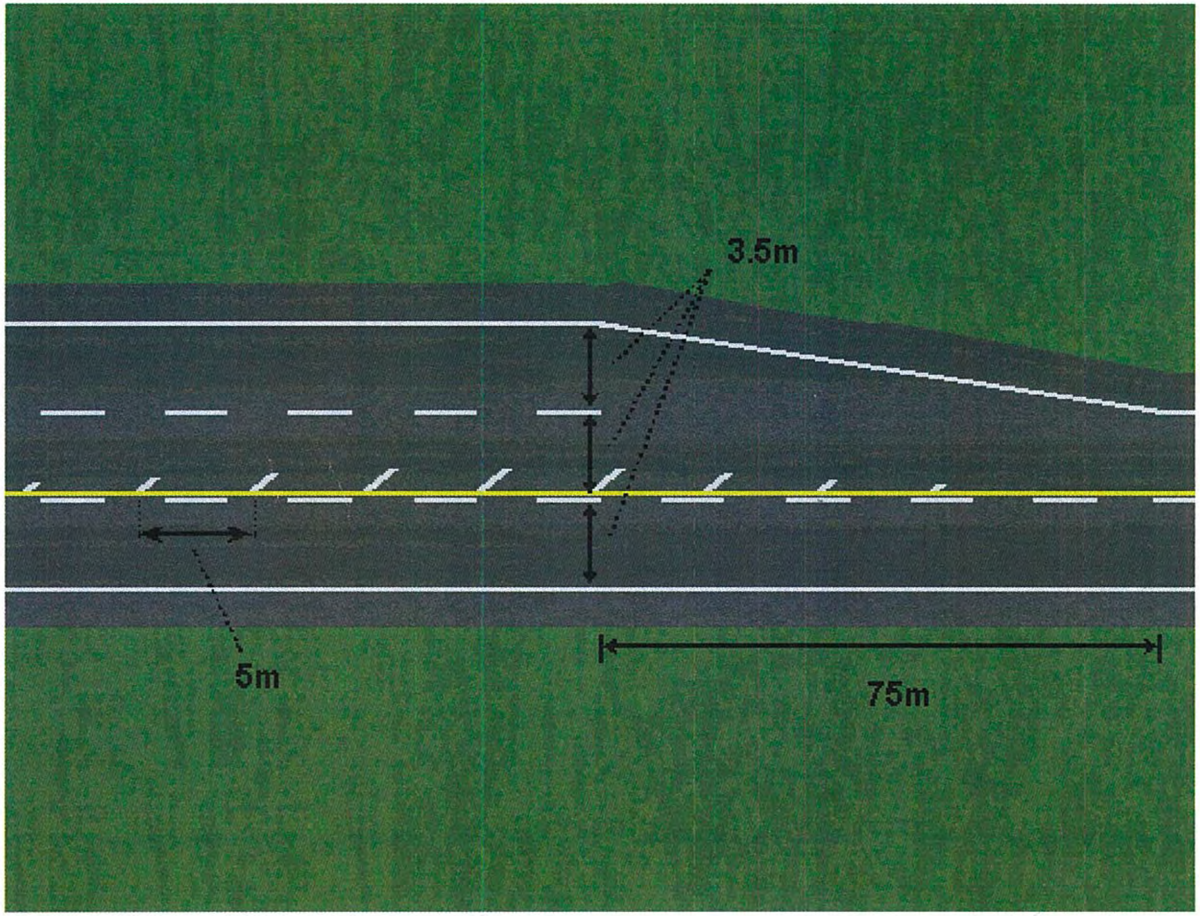
Table 5.8 provides participants' ratings for these treatments, and it shows, similar to the double herringbone, that this treatment was clearly popular with participants.

Table 5.8 Participant ratings of right herringbone and standard treatments on short tapers.

Paint Treatment	Right Herringbone		Standard	
Rating	**Mean**	**SD**	**Mean**	**SD**
Clarity	7.0	1.9	4.6	1.9
Effectiveness	6.6	1.9	4.1	1.9
Safety	6.1	2.2	4.1	1.9

Figure 5.30 Oblique scan (left) and screen shot of plan view (right) of the simulated right herringbone with short taper merge design.





Participants' comments included:

- *"I wasn't what they [the lines] were for. I tried to avoid driving on them which could be dangerous quite sure."*
- *"I found when driving that I was being pushed over to the left hand side of the road – encouraging the merge."*
- *"Not enough merge area."*
- *"This lane was great, it encouraged me left. Easy to understand."*

5.3 Conclusions and Suggested Changes for Passing Lane Merge Design

5.3.1 Questions on Merge Design

This phase (Stage 4) of the research aimed to address several questions about merge design:

- What was the effect of a blind merge compared to a straight merge?
- What was the effect of a short merge taper compared to a long taper (Austroads standard)?
- What was the effect of an early termination of the lane line compared to the standard that is currently on road?
- What was the effect of the paint treatments on driver behaviour?

5.3.2 Conclusions for Merge Design

The results outlined in Section 5.2 provided substantial information regarding the research questions. The key findings are as follows:

- Drivers tended to travel faster through blind merges than straight merges, even though their visibility was reduced.
- A long merge taper (Austroads standard) encouraged slow steady reductions in speed.
- Early termination of the lane line appeared to result in a decrease in speeds and a move to the left hand side of the road. However this effect is possibly related to differences in driver behaviour exhibited before the merge area.
- The double herringbone had little effect on driver behaviour with either short or long taper geometry, despite their popularity with participants. However, the right herringbone condition appeared to result in a shift to the left and the maintenance of closer following distances. Once again, the change in lateral displacement should be interpreted with some caution because driver behaviour exhibited differences in the pre-merge area.

The simulator-based testing has shown that geometric merge design (including correctly placing the merge in relation to the road geometry, and allowing for an appropriate taper length) is important in promoting appropriate driver behaviour at merges.

The alternative treatments tested (early termination of the lane line, or different paint treatments) either resulted in a negative impact on driver behaviour, inconclusive results, or no impact at all.

In addition, the negative reaction of most of the drivers to the early termination of the lane line also indicates that they would not be comfortable with this treatment on the road. Therefore the conclusion is that these types of alternative treatments should not substitute for optimal geometric design.

5.3.3 Suggested Changes to Merge Design

The following suggested changes resulted from the simulator testing results and from participant ratings.

- Ensure all merge tapers are constructed to current standards, i.e. with long taper lengths (Austroads standards may be more appropriate).
- Ensure that merges are adequately placed in relation to road geometry. Blind merges should be avoided if at all possible.

6. Suggestions for Improving Passing Lane Design

The following list summarises the suggested changes to passing lane design from Stages 3 and 4 (Chapters 4 and 5) of the research (overtaking in the opposing direction, and merge design) into a comprehensive outline of measures that could be taken to improve safety at passing lanes. In these Chapters there are limitations to the research that should be taken into consideration when interpreting the following suggestions.

In Chapter 4 (Stage 3), in some cases the environmental surveys of external conditions of the crash sites were conducted up to 5 years after the crash had occurred. Thus the results should be interpreted with some caution as the markings and geometry of some sites may have changed in this time. Also, as the Environmental Surveys were conducted at the crash sites at the locations that were stated in the crash report, the analyses may have been conducted some distance from where the driver actually began the overtaking manoeuvre.

In Chapter 5 (Stage 4) some of the differences in pre-merge behaviour mean that comparisons between treatments within the merge area should be interpreted with some caution. The difficulty in some cases is to establish whether the differences in behaviour resulted from these pre-merge discrepancies or from the treatment.

Further, more detailed study into the implications of individual suggestions should be undertaken before implementation of the changes suggested here is considered:

- Ensure all merge tapers are constructed to current standards, i.e. with long taper lengths.
- Ensure all shoulders comply with the Transit NZ minimum width of 1.5 m. Widening to a minimum of 2 m is preferred to provide an 'escape route' for drivers involved in potential crashes.
- Increase passing lane opportunities to reduce driver frustration and related increased risk taking.
- Consider widening lane used for the opposing lane to provide overtaking opportunities for downhill traffic.
- Install wide double yellow lines with vibraline on high-risk sections of 3-lane or multi-lane roads.
- Where traffic volumes are high, consider installing a solid median barrier between the opposing lane and the passing lane.
- Install warning signage at potentially hazardous areas where some confusion is likely about actual available sight distances, and where there is some uncertainty in which lane vehicles are to travel.

- Increase education to the motoring public about safe overtaking.
- Install warning signs at locations where poor driving conditions caused by adverse weather, such as icy conditions, occur.
- Remove 'pseudo' passing lanes, i.e. hatched shoulders, or treat the merge of such areas in the same manner as for passing lane merges.

7. References

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Appendices

Appendix A: Detailed Analysis of Crashes Using CAS

Crash ID	Action that occurred	Vehicle Types Involved	Weather/Road/ Light Conditions	Road Geometry	Comments (if any)
9853279 3/415/0.395	Driver (Female, 38) pulled out to pass on a broken yellow line. Lost control when a car came around the corner in the opposing direction even though it was in the left lane.	Driver overtaking car	Fine Dry Surface Dark	Hill Road Easy Curve	Driver appeared to panic even though the car was not in their lane. Was OT on a yellow line on a bend.
9712355 3/279/5.312	Driver (Female, 26) pulled out to overtake a truck in a passing lane in the opposing direction. Lost control on ice and crashed.	Driver overtaking truck	Fine Icy Surface Bright	Hill Road Straight	Suspect that speed might also have been involved.
9753417 3/279/5.262	Driver (Male, 26) pulled out to overtake a truck using the passing lane in the opposing direction. Lost control on ice and crashed.	Driver overtaking truck	Fine Icy Surface Twilight	Hill Road Straight	Same location as above. Again, it seems speed may have been too high for conditions.
9952909 3/279/3.077	Driver (left scene) overtook a vehicle using the opposing passing lane in the face of oncoming traffic. Vehicle being passed was forced off the road.	Driver overtaking car	Fine Dry Surface Dark	Flat Road Straight	
9713049 1N/915/2.51	Driver (left scene) overtook using a passing lane in the opposing direction. Was overtaking a large vehicle in the face of traffic. Vehicle being overtaken lost control and crashed.	Driver overtaking stock truck	Fine Dry Surface Dark	Hill Road Easy Curve	Driver left the scene without stopping. Overtook on a broken yellow line. Officer commented that yellow line should have started earlier and that a slight crest was affecting sight lines.

Crash ID	Action that occurred	Vehicle Types Involved	Weather/Road/ Light Conditions	Road Geometry	Comments (if any)
9650120 1N/741/5.966	Driver (left scene) overtook a car using an opposing passing lane (against a no-pass line). Forced car off the road.	Driver overtaking car towing boat	Light Rain Wet Surface Overcast	Hill Road Straight	Driver caused accident without actually being involved.
9910042 1N/780/2.041	Driver (Female, 67) overtook a vehicle and in doing so encroached on the opposing passing lane. Collided with three motorcyclists.	Driver overtaking ute	Light Rain Wet Road Overcast	Hill Road Easy Curve	Very severe accident.
2100081 1N/550/14.753	Driver (Male, 37) overtaking (towing) using opposing passing lane. Clipped car when returning to lane.	Driver (towing) overtaking car	Heavy Rain Wet Road Overcast	Hill Road Straight	Overtaking elderly (slow) driver.
9812261 1N/915/11.556	Driver (left scene) overtook using an opposing passing lane crossing solid yellow line in the face of traffic. Oncoming traffic swerved to avoid driver and crashed.	Driver overtaking a grader	Fine Dry Road Bright	Flat Road Straight	Appeared to be speed involved. Driver at fault did not stop. Crossed double yellow lines.
2150181 1N/903/2.041	Vehicle pulled over to avoid oncoming trucks in passing lanes. Driver (Male, 38) overtook him without sufficient room and collided with vehicle.	Truck overtaking a car	Fine Dry Surface Overcast	Flat Road Easy Curve	Driver perhaps failed to understand why vehicle pulled over.
9611689 1N/741/7.78	Driver (Male, 49) passed two vehicles on a blind corner using the opposing passing lane. Was parallel with vehicles when a car came around the corner in outside passing lane and collided with driver.	Driver overtaking a car	Light Rain Wet Road Dark	Hill Road Easy Curve	Overtook on a blind corner crossing a no-pass line.

Crash ID	Action that occurred	Vehicle Types Involved	Weather/Road/ Light Conditions	Road Geometry	Comments (if any)
2000156 1N/503/0.403	Driver (Female, 22) attempted to overtake another vehicle. Crossed no-pass lines into path of vehicle in opposing passing lane.	Driver overtaking car	Fine Dry Road Dark	Hill Road Easy Curve	Unlicensed driver and had been banned from driving. Crossing a no-pass line.
9900161 1N/576/10.144	Driver (Male, 26) passed truck in the face of oncoming traffic. Collided with on-coming vehicle.	Driver overtaking truck	Light Rain Wet Road Dark	Unknown Straight	Officer commented that visibility was poor.
9734080 1N/576/5.343	Driver (Male, 31) overtook vehicle using opposing passing lane. Hit vehicle that was coming up hill in outside lane.	Driver overtaking car	Light Rain Wet Road Overcast	Hill Road Straight	Officer commented that the road was downhill.
9950550 1N/780/1.243	Driver (Female, 32) attempted to overtake truck using passing lane in the opposing lane. Saw vehicle in outside passing lane, attempted to pull back into own lane. Hit the truck and spun out.	Driver overtaking truck	Fine Dry Road Bright	Hill Road Moderate Curve	Did not see vehicle in outside lane.
9900020 1N/485/12.597	Driver (Female, 32) overtook vehicle using passing lane in opposing direction and hit a car in outside passing lane head-on.	Driver overtaking car	Fine Dry Road Bright	Flat Road Easy Curve	Crash involved several vehicles.
9634028 1N/428/6.274	Driver (left scene) overtook vehicle using opposing passing lane. Caused cars in passing lane to swerve to avoid them and lose control.	Driver overtaking car	Fine Dry Road Dark	Flat Road Straight	Driver failed to stop at scene.

Crash ID	Action that occurred	Vehicle Types Involved	Weather/Road/ Light Conditions	Road Geometry	Comments (if any)
9804238 1N/485/13.073	Driver (Male, 73) attempted to overtake using oppcsing passing lane and collided head-on with a vehicle in the outside lane.	Driver overtaking truck	Fine Dry Road Bright	Flat Road Straight	Officer states that there was insufficient visibility or a clear road.
9754247 2/946/12.259	Driver (Male, 17) attempted to overtake another vehicle using opposing passing lanes. Swerved to avoid oncoming vehicle and hit car they were overtaking.	Driver overtaking car	Fine Wet Road Overcast	Flat Road Straight	Learner driver. Speed involved.
9852689 1N/931/9.746	Driver (Female, 29) pulled out to overtake using the opposing passing lane at the same time as another vehicle braked and lost control.	Driver overtaking car	Fine Dry Road Dark	Hill Road Straight	Difficult to assess fault. Both vehicles attempting to pass on double yellow line. Officer states speed involved.
9654963 2/691/6.682	Driver (Female, 31) attempted to overtake using opposing passing lane, did not have clear visibility due to curve, lost control trying to avoid oncoming vehicle.	Driver overtaking car	Fine Dry Road Twilight	Flat Road Moderate Curve	Driver attempted to overtake on a moderate curve and a downhill area.
2111761 2/691/5.612	Driver (Female, 33) attempted to pass truck using opposing passing lane. Vehicle appeared in outside lane, driver attempted to avoid vehicle, lost control, and hit truck.	Driver overtaking truck	Fine Wet Road Overcast	Hill Road Straight	Lost control trying to avoid oncoming vehicle.
9801456 2/130/0.436	Driver (Male, 22) overtook in opposing passing lane, crossing no-pass lines. Lost control and collided with vehicle in passing lane.	Driver overtaking bus	Fine Dry Road Bright	Hill road Easy Curve	Learner licence. Driver crossing no-pass lines.

Crash ID	Action that occurred	Vehicle Types Involved	Weather/Road/ Light Conditions	Road Geometry	Comments (if any)
9654045 2/931/2	Driver (Male, 22) attempted to overtaking truck using opposing passing lane. Collided with vehicle in the outside lane.	Driver overtaking truck	Light Rain Wet Road Overcast	Hill Road Easy Curve	Driver travelling downhill. Driver on restricted licence. Officer commented that it was unsafe to pass.
9711183 2/931/1.899	Driver (Female, 75) attempted to overtake truck using opposing passing lane. Encountered vehicle in lane, car in lane swerved and vehicles sideswiped.	Driver overtaking truck	Fine Dry Road Bright	Hill Road Severe Curve	Sharp right corner. Poor visibility.
9812434 2/905/11.179	Driver (Male, 49), attempted to overtake using opposing passing lane. Car rounded corner in outside lane. Driver lost control and crashed.	Driver overtaking two cars and a ute towing a trailer	Light Rain Wet Road Overcast	Hill Road Moderate Curve	Appeared to be speed involved and poor sight lines.
2052590 1N/953/3.416	Crash report provides insufficient detail. Driver in outside passing lane driven off road by unknown driver.	Unknown	Fine Dry Road Dark	Flat Road Easy Curve	
2151119 1N/931/9.704	Driver (Male, 25) overtook car using opposing passing lane. Pulled in too early and sideswiped vehicle being overtaken.	Driver overtaking car	Light Rain Wet Road Overcast	Hill Road Straight	Overtook on double yellow lines. Officer states that driver deliberately rammed vehicle.
9951406 1N/953/7.883	Driver (left scene) attempted to overtake truck using opposing passing lane. Cut in front of truck and clipped it.	Driver overtaking truck	Fine Dry Road Dark	Hill Road Easy Curve	Driver failed to stop. Road geometry meant driver was overtaking downhill.

Crash ID	Action that occurred	Vehicle Types Involved	Weather/Road/ Light Conditions	Road Geometry	Comments (if any)
9812714 3/250/4.769	Car stopped to turn into side road across passing lane. Driver (Male, 25) attempted to overtake using passing lane and collided with car.	Driver overtaking car towing trailer	Fine Dry Road Overcast	Hill Road Straight	Very poor visibility. Driver was on motorcycle. Overtaking over double yellow lines.
9903471 29/21/14.56	Driver (Female, 41) pulled out to pass a line of traffic by using the opposing passing lane. Encountered vehicles in the outside lane, which resulted in a head-on collision.	Driver probably overtaking truck	Fine Dry Road Bright	Hill Road Straight	
9838932 1N/393/13.962	Driver (left scene) pulled into passing lane causing car using lane to swerve and lose control.	Driver overtaking car	Fine Dry Road Overcast	Flat Road Straight	Officer commented that no yellow line to stop opposing traffic.
2001703 10/0/10.18	Driver (Male, 42) attempted to overtake vehicles in front using opposing passing lane. However, pulled out into vehicle already using passing lane to overtake him.	Driver overtaking car	Fine Dry road Bright	Hill Road Straight	Probably did not use his mirrors. No evidence of vehicles using passing lane in 'correct' direction.
9900128 1N/203/7.486	Driver (Male, 46) attempted to overtake using a passing lane in the opposing direction. Collided with vehicle using outside lane.	Driver overtaking car	Fine Dry Road Bright	Hill Road Moderate Curve	Was overtaking on a corner in the face of traffic.
9634455 17/16/14.736	Driver (Male, 38) overtook truck using an opposing passing lane and crossing double yellow lines. Cut in too soon and clipped truck.	Driver overtaking truck	Fine Dry road Bright	Hill Road Straight	Overtaking on double yellow lines, downhill.

Crash ID	Action that occurred	Vehicle Types Involved	Weather/Road/ Light Conditions	Road Geometry	Comments (if any)
9602621 1N/173/0.5	Driver (left scene) overtook truck using an opposing passing lane and had to pull back into own lane due to oncoming traffic. In doing so clipped truck causing it to crash.	Driver overtaking truck	Fine Wet Road Dark	Hill road Straight	Officer states that there was insufficient room to overtake truck.
9834042 1N/393/8.092	Driver (Male, 44) lost control after overtaking using opposing passing lane.	Driver overtaking car	Fine Dry Road Overcast	Hill Road Straight	Officer states that driver was overtaking in an unsafe area.
2111040 45/15/3.007	Driver (Male, 20) overtook truck using opposing passing lane. Swerved to avoid oncoming vehicle, lost control and crashed.	Driver overtaking truck	Fine Dry Road Bright Sun	Hill Road Easy Curve	Overtaking on double yellow lines. Overtaking on crest of hill, therefore poor sight lines.
9612705 58/0/5.253	Driver (Male, 18) passed vehicle using opposing passing lane. Lost control and crashed.	Driver overtaking car	Fine Dry Road Dark	Hill Road Straight	Officer commented that the vehicle may have had a steering problem. Front right tyre flat.
955124 58/0/7.353	Driver (Male, 25) passed vehicle using opposing passing lane. Struck a vehicle using the passing lane (just clipped).	Driver overtaking car	Fine Dry Road Bright Sun	Hill Road Straight	Driver stated that he could not see the vehicle as it was obscured by a truck until it pulled out.

Appendix B: Physical Attributes of Survey Sites

Site Location	Traffic Volume (vpd)	% Heavy Vehicles
SH 10 (0/10.18) Pakaraka (West of Paihia)	5,400	Unknown
SH 17 (16/14.736) Albany Hill	16,000	Unknown
SH1 (173/0.5) S of Whangarei	10,000	8%
SH1 (203/7.486) Waipu	6,500	8%
SH 1 (393/13.962) S of Bombay	16,000	10%
SH 1 (428/6.274) N of Gordonton	15,300	10%
SH 1 (485/12.597) Cambridge	18,400	10%
SH 1 (503/0.403) Pairere (S of Cambridge)	8,000	10%
SH1 (550/14.753) Tokoroa	9,300	5%
SH 1 (576/10.144) Atiamuri	5,500	5%
SH 1 (741/5.966) Turangarere (S of Waiouru)	4,500	11%
SH 1 (741/7.78) Turangarere (S of Waiouru)	4,500	11%
SH1 (780/1.243) Mangaweka	5,000	11%
SH1 (780/2.041) Mangaweka	5,000	11%
SH 2 (130/0.436) S of Katikati	9,100	7%
SH 29 (21/14.56) W of Tauranga	10,100	6%
SH 3 (250/4.769) Bet. New Plymouth & Inglewood	10,000	11%
SH 3 (279/3.077) Near Stratford	13,500	10%
SH 3 (279/5.262) Near Stratford	13,500	10%
SH 3 (279/5.312) Near Stratford	13,500	10%
SH 3 (415/0.395) Bet. Wanganui & Turakina	7,000	13%

Appendix C: Posted Speed Limits & Vehicle Speeds at Survey Sites

Site Location	Posted Speed Limit (kph)	Average Vehicle Speed (kph)	85th Percentile Vehicle Speed (kph)
SH 10 (0/10.18) Pakaraka (W of Paihia)	100	97	104
SH 17 (16/14.736) Albany Hill	50 (80 just past site)	69	77
SH1 (173/0.5) S of Whangarei	100	101	108
SH1 (203/7.486) Waipu	100	94	104
SH 1 (393/13.962) S of Bombay	100 (70, roadworks)	90	99
SH 1 (428/6.274) N of Gordonton	100	87	95
SH 1 (485/12.597) Cambridge	100	97	104
SH 1 (503/0.403) Pairere (S of Cambridge)	100	94	100
SH1 (550/14.753) Tokoroa	100	96	107
SH 1 (576/10.144) Atiamuri	100	88	98
SH 1 (741/5.966) Turangarere (S of Waiouru)	100	97	109
SH 1 (741/7.78) Turangarere (S of Waiouru)	100	93	104
SH1 (780/1.243) Mangaweka	100	94	101
SH1 (780/2.041) Mangaweka	100	81	91
SH 2 (130/0.436) S of Katikati	100	89	97
SH 29 (21/14.56) W of Tauranga	100	85	97
SH 3 (250/4.769) Bet. New Plymouth and Inglewood	100	95	103
SH 3 (279/3.077) Near Stratford	100	98	106
SH 3 (279/5.262) Near Stratford	100	98	107
SH 3 (279/5.312) Near Stratford	100	98	105
SH 3 (415/0.395) Bet. Wanganui & Turakina	100	92	102

Appendix D: Carriageway & Lane Widths at Survey Sites

Site Location	Carriageway Width (m)	Width of Single Lane Opposing Direction (m)	Width of Kerbside OT Lane (m)	Width of Middle OT Lane (m)
SH 10 (0/10.18) Pakaraka (W of Paihia)	14.1	3.55	3.4	3.3
SH 17 (16/14.736) Albany Hill	12.1	3.6	3.5	3.5
SH1 (173/0.5) S of Whangarei	13.65	3.7	3.3	3.4
SH1 (203/7.486) Waipu	11.2	3.8	3.2	3.2
SH 1 (393/13.962) S of Bombay	11	3.5	3.5	3.5
SH 1 (428/6.274) N of Gordonton	13	3.5	3.5	3.5
SH 1 (485/12.597) Cambridge	13	3.5	3.5	3.5
SH 1 (503/0.403) Pairere (S of Cambridge)	13	3.5	3.5	3.5
SH1 (550/14.753) Tokoroa	13.5	3.5	3.5	3.5
SH 1 (576/10.144) Atiamuri	11.5	3.5	3.5	3.5
SH 1 (741/5.966) Turangarere (S of Waiouru)	14.2	3.7	3.5	3.45
SH 1 (741/7.78) Turangarere (S of Waiouru)	14.85	3.7	3.5	3.65
SH1 (780/1.243) Mangaweka	12.4	3.35	3.35	3.5
SH1 (780/2.041) Mangaweka	12.55	3.5	3.35	3.6
SH 2 (130/0.436) S of Katikati	13	3.5	3.5	2.5
SH 29 (21/14.56) W of Tauranga	13.5	3.5	3.5	3.5
SH 3 (250/4.769) Bet. New Plymouth and Inglewood	17.6	3.6	3.6	3.5
SH 3 (279/3.077) Near Stratford	15	3.6	3.55	3.65
SH 3 (279/5.262) Near Stratford	12.15	3.95	3.5	3.25
SH 3 (279/5.312) Near Stratford	12.1	3.9	3.5	3.2
SH 3 (415/0.395) Bet. Wanganui & Turakina	15.2	3.75	3.3	3.75

Appendix E: Shoulder Widths at Survey Sites

*OT Lane – overtaking lane on the passing lane side

Site Location	Sealed Shoulder Width (m)		Additional Gravel Shoulder (m)		Distance To Ditch (if present) from seal edge (m)		Distance To Bank/Guardrail (if present) from seal edge (m)		Verge Width (m)	
	OT Lane* Side	Opposing Side	OT Lane Side	Opposing Side	OT Lane Side	Opposing Side	OT Lane Side	Opposing Side	OT Lane Side	Opposing Side
SH 10 (0/10.18) Pakaraka (W of Paihia)	0.8	2.7	0	0	1.5	1	3	N/A	1.5	2.6
SH 17 (16/14.736) Albany Hill	1	0.5	0	0.5	1.5	1	N/A	5.5	1	1.5
SH1 (173/0.5) S of Whangarei	1.4	1.7	0.3	0.3	N/A	N/A	8	4	8	4
SH1 (203/7.486) Waipu	0.7	0.3	1	1	3	1.5	6	6	3	2.5
SH 1 (393/13.962) S of Bombay	0	1	0	0	N/A	N/A	N/A	N/A	2	2
SH 1 (428/6.274) N of Gordonton	1	2	0	0	N/A	N/A	N/A	3	3	2

Site Location	Shoulder Width (m)		Additional Gravel Shoulder (m)		Dist To Ditch (if present) from seal edge (m)		Dist To Bank/Guardrail (if present) from seal edge (m)		Verge Width (m)	
	OT Lane Side	Opposing Side	OT Lane Side	Opposing Side	OT Lane Side	Opposing Side	OT Lane Side	Opposing Side	OT Lane Side	Opposing Side
SH 1 (485/12.597) Cambridge	1	1.5	0	0	N/A	4	N/A	N/A	4	3
SH 1 (503/0.403) Pairere (S of Cambridge)	1 .	1.5	0	0	N/A	N/A	1	1	1	1
SH1 (550/14.753) Tokoroa	1.5	1.5	0	0	1	4	N/A	N/A	0	4
SH 1 (576/10.144) Atiamuri	0.9	1	0	0	1.5	0.9	N/A	N/A	0.5	7
SH 1 (741/5.966) Turangarere (S of Waiouru)	1.8	1.6	0	1.8	3.3	1.8	3	N/A	0	0
SH 1 (741/7.78) Turangarere (S of Waiouru)	2.3	1.65	0	0	1.1	N/A	2.8	N/A	0	0

Site Location	Shoulder Width (m)		Additional Gravel Shoulder (m)		Dist To Ditch (if present) from seal edge (m)		Dist To Bank/Guardrail (if present) from seal edge (m)		Verge Width (m)	
	OT Lane Side	Opposing Side	OT Lane Side	Opposing Side	OT Lane Side	Opposing Side	OT Lane Side	Opposing Side	OT Lane Side	Opposing Side
SH1 (780/1.243) Mangaweka	0.7	1.3	0	0	N/A	N/A	1.2	4	1.2	3.7
SH1 (780/2.041) Mangaweka	1.05	1.3	0	0	4	N/A	N/A	1.3	4	1.5
SH 2 (130/0.436) S of Katikati	1.5	1.5	0	0.5	N/A	N/A	3.5	N/A	2	4
SH 29 (21/14.56) W of Tauranga	3	1.5	0	0	N/A	N/A	2.5	1	0	0
SH 3 (250/4.769) Bet. New Plymouth and Inglewood	1.8	1.6	0	0	N/A	N/A	0.75	1.5	0	0
SH 3 (279/3.077) Near Stratford	1.4	1.7	0	0	4	N/A	6	5.5	4	5.5

Site Location	Shoulder Width (m)		Additional Gravel Shoulder (m)		Dist To Ditch (if present) from seal edge (m)		Dist To Bank/Guardrail (if present) from seal edge (m)		Verge Width (m)	
	OT Lane Side	Opposing Side	OT Lane Side	Opposing Side	OT Lane Side	Opposing Side	OT Lane Side	Opposing Side	OT Lane Side	Opposing Side
SH 3 (279/5.262) Near Stratford	0.5	1.15	0	0	N/A	N/A	1.5	5.5	1.5	5.5
SH 3 (279/5.312) Near Stratford	0.6	1.1	0	0	1.5	1.5	1.5	5.5	1.5	1.5
SH 3 (415/0.395) Bet. Wanganui & Turakina	3.75	1.85	0	0	4.25	7	4.75	N/A	0	7

Appendix F: Road Gradients & Curvatures at Survey Sites

Site Location	Gradient		Curvature		
	Level	Hilly (5–15%)	At Site	Beyond Site on Opposing Lane	Prior to Site on Opposing Lane
SH 10 (0/10.18) Pakaraka (W of Paihia)		(uphill OT lane)	Straight	Easy Curve	Moderate Curve
SH 17 (16/14.736) Albany Hill		(uphill OT lane)	Easy Curve	Severe Curve	Straight Curve
SH1 (173/0.5) S of Whangarei		(uphill OT lane)	Easy Curve	Straight-Easy Curve	Moderate Curve
SH1 (203/7.486) Waipu		(uphill OT lane)	Straight	Easy Curve	Easy Curve
SH 1 (393/13.962) S of Bombay	Level		Straight	Straight	Straight
SH 1 (428/6.274) N of Gordonton	Level		Straight	Straight	Straight
SH 1 (485/12.597) Cambridge	Level		Easy	Moderate Curve	Moderate Curve
SH 1 (503/0.403) Pairere (S of Cambridge)		(uphill OT lane)	Easy	Easy Curve	Easy Curve
SH1 (550/14.753) Tokoroa		(uphill OT lane)	Straight	Unknown	Unknown
SH 1 (576/10.144) Atiamuri		(uphill OT lane)	Easy	Severe Curve	Easy Curve
SH 1 (741/5.966) Turangarere (S of Waiouru)		(uphill OT lane)	Straight	Moderate Curve	Moderate Curve
SH 1 (741/7.78) Turangarere (S of Waiouru)		(uphill OT lane)	Moderate Curve	Easy Curve	Moderate Curve
SH1 (780/1.243) Mangaweka	Level		Moderate Curve	Easy Curve	Moderate Curve
SH1 (780/2.041) Mangaweka		(uphill OT lane)	On Crest	Moderate Curve	Severe Curve
SH 2 (130/0.436) S of Katikati	Level		Easy Curve	Easy Curve	Easy Curve
SH 29 (21/14.56) W of Tauranga		(uphill OT lane)	Straight	Easy Curve	Straight
SH 3 (250/4.769) Bet. New Plymouth & Inglewood		Site at Crest of Hill	Straight	Straight	Straight to Easy Curve
SH 3 (279/3.077) Near Stratford	Level		Straight	Moderate Curve	Straight
SH 3 (279/5.262) Near Stratford	Level		Straight	Straight	Straight
SH 3 (279/5.312) Near Stratford	Level		Straight	Straight	Straight
SH 3 (415/0.395) Bet. Wanganui & Turakina		(uphill OT lane)	Straight	Easy	Severe

Appendix G: Estimated Sight Distances Before & After Survey Sites

Site Location	Estimated Sight Distances prior to Site (Opposing Side) (m)	Estimated Sight Distances beyond Site (Opposing Side) (m)	Estimated Distance to start of O/T lane Diverge (m)
SH 10 (0/10.18) Pakaraka (W of Paihia)	100	700	250
SH 17 (16/14.736) Albany Hill	300	200	Unknown
SH1 (173/0.5) S of Whangarei	750	700	100
SH1 (203/7.486) Waipu	600	400	200
SH 1 (393/13.962) S of Bombay	1000	1000	> 1000
SH 1 (428/6.274) N of Gordonton	500	400	50
SH 1 (485/12.597) Cambridge	250	300	>1000
SH 1 (503/0.403) Pairere (S of Cambridge)	400	200	500
SH1 (550/14.753) Tokoroa	1500	700	Unknown
SH 1 (576/10.144) Atiamuri	100	200	>1000
SH 1 (741/5.966) Turangarere (S of Waiouru)	250	250	Unknown
SH 1 (741/7.78) Turangarere (S of Waiouru)	200	350	250
SH1 (780/1.243) Mangaweka	300	300	150
SH1 (780/2.041) Mangaweka	100	100	Unknown
SH 2 (130/0.436) S of Katikati	550	300	20
SH 29 (21/14.56) W of Tauranga	800	500	50
SH 3 (250/4.769) Bet. New Plymouth and Inglewood	100	125	At right turn bay on opposing side
SH 3 (279/3.077) Near Stratford	200	300	Start of hatched area for right turn bay on opposing side
SH 3 (279/5.262) Near Stratford	200	800	Unknown
SH 3 (279/5.312) Near Stratford	250	800	Unknown
SH 3 (415/0.395) Bet. Wanganui & Turakina	175	300	Unknown

Appendix H: Paintwork at Survey Sites

Site Location	CentreLine			Edgelines
	Double Yellow	Single Yellow Dashed Yellow Opposing	Single Yellow Dashed White Opposing	
SH 10 (0/10.18) Pakaraka (W of Paihia)	✔			Yes
SH 17 (16/14.736) Albany Hill	✔			Yes
SH1 (173/0.5) S of Whangarei			✔	Yes
SH1 (203/7.486) Waipu			✔	Yes
SH 1 (393/13.962) S of Bombay			✔	Yes
SH 1 (428/6.274) N of Gordonton			✔	Yes
SH 1 (485/12.597) Cambridge	✔			Yes
SH 1 (503/0.403) Pairere (S of Cambridge)	✔			Yes
SH1 (550/14.753) Tokoroa			✔	Yes
SH 1 (576/10.144) Atiamuri			✔	Yes
SH 1 (741/5.966) Turangarere (S of Waiouru)		✔		Yes
SH 1 (741/7.78) Turangarere (S of Waiouru)	✔			Yes
SH1 (780/1.243) Mangaweka			✔	Yes
SH1 (780/2.041) Mangaweka	✔			Yes
SH 2 (130/0.436) S of Katikati	✔			Yes
SH 29 (21/14.56) W of Tauranga			✔	Yes
SH 3 (250/4.769) Bet. New Plymouth and Inglewood	✔			Yes
SH 3 (279/3.077) Near Stratford	✔			Yes
SH 3 (279/5.262) Near Stratford			✔	Yes
SH 3 (279/5.312) Near Stratford			✔	Yes
SH 3 (415/0.395) Bet. Wanganui & Turakina			✔	Yes

Appendix I: Closing Speeds at Survey Sites

Site Location	85th Percentile Speeds (kph)			Closing Speeds (kph)	Estimated available SD*	Recommended ESD**	% of Recommended ESD available***	Double Yellow Line	Diverge or RT Bay present?	Topography
	Average	Passing lane (Generally uphill)	Opposing Lane (Generally downhill)							
SH 10 (0/10.18) Pakaraka (W of Paihia)	104	104	105	209	800	1,000	80	Yes	Diverge	Straight, then easy curve
SH 17 (16/14.736) Albany Hill	77	80	74	154	500	520	96	Yes		Easy curve, then tightening
SH1 (173/0.5) S of Whangarei	108	112	104	216	1,450	1,100	132		Diverge	Straight, then easy curve
SH1 (203/7.486) Waipu	104	105	103	208	1,000	1,000	100		Diverge	Long easy curve
SH 1 (393/13.962) S of Bombay	99	102	95	197	2,000	920	217			Long straight
SH 1 (428/6.274) N of Gordonton	95	99	92	191	900	800	113		Diverge	Long straight
SH 1 (485/12.597) Cambridge	104	108	101	209	550	1,000	55%	Yes		Easy curve, level
SH 1 (503/0.403) Pairere (S of Cambridge)	100	100	99	199	600	920	65%	Yes		Easy curve

Site Location	85th Percentile Speeds (kph)			Closing Speeds (kph)	Estimated available SD*	Recommended ESD**	% of Recommended ESD available***	Double Yellow Line	Diverge or RT Bay present?	Topography
	Average	Passing lane (Generally uphill)	Opposing Lane (Generally downhill)							
SH1 (550/14.753) Tokoroa	107	107	106	213	2,200	1,200	183			Long straight
SH 1 (576/10.144) Atiamuri	98	95	101	196	300	900	33			Easy curve, then onto a straight section
SH 1 (741/5.966) Turangarere (S of Waiouru)	109	106	113	219	500	1,100	45			Straight, then moderate
SH 1 (741/7.78) Turangarere (S of Waiouru)	104	102	107	209	550	1,000	55	Yes	Diverge	Moderate curve, then easing
SH1 (780/1.243) Mangaweka	101	103	99	202	600	920	65		Diverge	Moderate curve, then easing
SH1 (780/2.041) Mangaweka	91	95	87	182	200	770	26	Yes		On crest, with moderate curves both sides
SH 2 (130/0.436) S of Katikati	97	100	94	194	850	1,020	83	Yes	Diverge	Easy curve
SH 29 (21/14.56) W of Tauranga	97	94	100	194	1,300	1,020	127			Straight, then easy curve

Site Location	85th Percentile Speeds (kph)			Closing Speeds (kph)	Estimated available SD*	Recommended ESD**	% of Recommended ESD available***	Double Yellow Line	Diverge or RT Bay present?	Topography
	Average	Passing lane (Generally uphill)	Opposing Lane (Generally downhill)							
SH 3 (250/4.769) Bet. New Plymouth and Inglewood	103	105	101	206	225	950	24	Yes	RT Bay	On crest, straight
SH 3 (279/3.077) Near Stratford	106	103	109	212	510	1,030	50	Yes	RT Bay	Straight, then moderate curve, level
SH 3 (279/5.262) Near Stratford	107	109	104	213	1,000	1,020	98			Long straight, level
SH 3 (279/5.312) Near Stratford	105	106	104	210	1,050	1,000	105			Long straight, level
SH 3 (415/0.395) Bet. Wanganui & Turakina	102	99	106	205	475	930	51			Straight, then easy curve
Average	**101**	**102**	**100**	**202**						

* Sight Distance (SD) estimated at the crash site, which may not reflect exact location of driver when the decision to overtake was made.

** ESD - Estimated Sight Distance is the minimum sight distance which is adequate to encourage a given proportion of drivers to commence an overtaking manoeuvre. ESD establishes a length of road as a potential overtaking zone. Refer Austroads Rural Road Design, Guide to the Geometric Design of Rural Roads, Part 6.7, Overtaking Requirements.

*** ESD available for the first driver trailing a slower vehicle. Second and other drivers to overtake will have a reduced SD available, and will need to have the Continuation Sight Distance (CSD) available (approx 50% ESD).

Appendix J: Descriptive Statistics from Merge Lane Design Analysis

Table J1. Comparisons of Blind Merge and Straight Merge

					95% Confidence Interval	
TREATMEN	POSITION	MEASURE	Mean	Std. Error	Lower Bound	Upper Bound
Straight	1	1	105.043	1.336	102.314	107.772
		2	3.783	.289	3.192	4.373
		3	2.077	.221	1.625	2.530
	2	1	102.819	1.391	99.978	105.660
		2	2.720	.265	2.178	3.262
		3	1.398	.219	.950	1.846
	3	1	95.968	1.811	92.270	99.666
		2	2.617	.257	2.092	3.142
		3	1.344	.203	.929	1.759
	4	1	85.591	1.617	82.289	88.893
		2	1.490	.147	1.189	1.790
		3	1.166	.207	.744	1.588
	5	1	81.049	1.212	78.575	83.524
		2	2.564	.336	1.877	3.251
		3	1.314	.269	.764	1.864
Blind	1	1	101.135	.873	99.353	102.918
		2	2.802	.300	2.189	3.415
		3	2.018	.308	1.388	2.647
	2	1	100.794	1.255	98.231	103.357
		2	3.236	.280	2.664	3.809
		3	1.557	.242	1.064	2.050
	3	1	99.680	1.958	95.681	103.679
		2	3.144	.287	2.558	3.731
		3	1.644	.279	1.074	2.213
	4	1	95.447	2.070	91.221	99.674
		2	1.632	.142	1.341	1.923
		3	1.349	.274	.789	1.908
	5	1	92.468	2.386	87.596	97.340
		2	1.556	.139	1.272	1.840
		3	1.701	.679	.314	3.087

Table J2. Effect of Merge Lane Taper Length.

TREATMEN	POSITION	MEASURE	Mean	Std. Error	95% Confidence Interval Lower Bound	Upper Bound
Long	1	1	101.135	.873	99.353	102.918
		2	2.802	.300	2.189	3.415
		3	2.018	.308	1.388	2.647
	2	1	100.794	1.255	98.231	103.357
		2	3.236	.280	2.664	3.809
		3	1.557	.242	1.064	2.050
	3	1	99.680	1.958	95.681	103.679
		2	3.144	.287	2.558	3.731
		3	1.644	.279	1.074	2.213
	4	1	95.447	2.070	91.221	99.674
		2	1.632	.142	1.341	1.923
		3	1.349	.274	.789	1.908
	5	1	92.468	2.386	87.596	97.340
		2	1.556	.139	1.272	1.840
		3	1.701	.679	.314	3.087
Short	1	1	103.417	1.500	100.353	106.481
		2	2.639	.306	2.013	3.264
		3	1.693	.280	1.121	2.265
	2	1	102.279	2.282	97.619	106.939
		2	2.906	.301	2.292	3.521
		3	1.783	.407	.952	2.613
	3	1	97.685	2.138	93.318	102.051
		2	3.119	.254	2.600	3.638
		3	2.569	.615	1.313	3.826
	4	1	96.682	1.976	92.646	100.718
		2	2.029	.096	1.833	2.224
		3	2.661	.658	1.317	4.004
	5	1	99.027	1.799	95.354	102.701
		2	1.548	.078	1.389	1.706
		3	4.569	.911	2.709	6.429

Table J3. Effect of Early Centre Line Termination

TREATMEN	POSITION	MEASURE	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Standard	1	1	101.135	.873	99.353	102.918
		2	2.802	.300	2.189	3.415
		3	2.018	.308	1.388	2.647
	2	1	100.794	1.255	98.231	103.357
		2	3.236	.280	2.664	3.809
		3	1.557	.242	1.064	2.050
	3	1	99.680	1.958	95.681	103.679
		2	3.144	.287	2.558	3.731
		3	1.644	.279	1.074	2.213
	4	1	95.447	2.070	91.221	99.674
		2	1.632	.142	1.341	1.923
		3	1.349	.274	.789	1.908
	5	1	92.468	2.386	87.596	97.340
		2	1.556	.139	1.272	1.840
		3	1.701	.679	.314	3.087
Early	1	1	108.306	1.805	104.620	111.992
		2	2.064	.218	1.618	2.510
		3	1.872	.184	1.495	2.248
	2	1	105.020	1.943	101.052	108.989
		2	1.961	.236	1.478	2.444
		3	1.963	.278	1.395	2.531
	3	1	98.526	2.537	93.344	103.707
		2	2.895	.236	2.412	3.377
		3	2.255	.250	1.746	2.765
	4	1	94.941	2.791	89.241	100.641
		2	2.310	.118	2.070	2.550
		3	2.261	.368	1.509	3.013
	5	1	91.827	1.833	88.084	95.571
		2	2.305	.223	1.850	2.760
		3	2.563	.567	1.406	3.720

Table J4. Effect of Double Herringbone with Long Taper

					95% Confidence Interval	
TREATMEN	POSITION	MEASURE	Mean	Std. Error	Lower Bound	Upper Bound
Standard	1	1	101.135	.873	99.353	102.918
		2	2.802	.300	2.189	3.415
		3	2.018	.308	1.388	2.647
	2	1	100.794	1.255	98.231	103.357
		2	3.236	.280	2.664	3.809
		3	1.557	.242	1.064	2.050
	3	1	99.680	1.958	95.681	103.679
		2	3.144	.287	2.558	3.731
		3	1.644	.279	1.074	2.213
	4	1	95.447	2.070	91.221	99.674
		2	1.632	.142	1.341	1.923
		3	1.349	.274	.789	1.908
	5	1	92.468	2.386	87.596	97.340
		2	1.556	.139	1.272	1.840
		3	1.701	.679	.314	3.087
Double Herring	1	1	102.563	1.306	99.895	105.230
		2	3.122	.290	2.529	3.715
		3	1.435	.335	.752	2.119
	2	1	103.661	1.607	100.378	106.943
		2	3.564	.243	3.068	4.060
		3	1.320	.257	.795	1.846
	3	1	99.318	2.290	94.640	103.995
		2	3.487	.198	3.084	3.890
		3	1.153	.214	.717	1.589
	4	1	93.908	2.255	89.303	98.514
		2	1.463	.127	1.203	1.722
		3	1.035	.213	.600	1.471
	5	1	92.983	2.507	87.863	98.102
		2	1.547	.102	1.338	1.756
		3	1.180	.336	.495	1.865

Table J5. Effect of Double Herringbone with Short Taper

TREATMEN	POSITION	MEASURE	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Double Herring	1	1	103.417	1.500	100.353	106.481
		2	2.639	.306	2.013	3.264
		3	1.693	.280	1.121	2.265
	2	1	102.279	2.282	97.619	106.939
		2	2.906	.301	2.292	3.521
		3	1.783	.407	.952	2.613
	3	1	97.685	2.138	93.318	102.051
		2	3.119	.254	2.600	3.638
		3	2.569	.615	1.313	3.826
	4	1	96.682	1.976	92.646	100.718
		2	2.029	.096	1.833	2.224
		3	2.661	.658	1.317	4.004
	5	1	99.027	1.799	95.354	102.701
		2	1.548	.078	1.389	1.706
		3	4.569	.911	2.709	6.429
Standard	1	1	104.640	1.839	100.885	108.395
		2	3.015	.282	2.438	3.591
		3	1.985	.476	1.014	2.957
	2	1	103.513	1.674	100.095	106.931
		2	3.060	.292	2.464	3.656
		3	2.532	.518	1.474	3.591
	3	1	97.819	1.953	93.830	101.807
		2	3.444	.192	3.052	3.835
		3	2.797	.608	1.556	4.038
	4	1	96.692	1.965	92.678	100.705
		2	1.821	.075	1.667	1.975
		3	2.946	.671	1.576	4.316
	5	1	100.869	1.888	97.013	104.724
		2	1.400	.096	1.204	1.596
		3	4.739	.929	2.842	6.637

Table J6. Effect of Right Herringbone with Short Taper

TREATMEN	POSITION	MEASURE	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Standard	1	1	103.417	1.500	100.353	106.481
		2	2.639	.306	2.013	3.264
		3	1.693	.280	1.121	2.265
	2	1	102.279	2.282	97.619	106.939
		2	2.906	.301	2.292	3.521
		3	1.783	.407	.952	2.613
	3	1	97.685	2.138	93.318	102.051
		2	3.119	.254	2.600	3.638
		3	2.569	.615	1.313	3.826
	4	1	96.682	1.976	92.646	100.718
		2	2.029	.096	1.833	2.224
		3	2.661	.658	1.317	4.004
	5	1	99.027	1.799	95.354	102.701
		2	1.548	.078	1.389	1.706
		3	4.569	.911	2.709	6.429
Right Herring	1	1	108.730	1.574	105.516	111.944
		2	2.048	.223	1.593	2.503
		3	1.756	.195	1.358	2.154
	2	1	104.615	1.784	100.972	108.259
		2	2.105	.245	1.604	2.606
		3	1.624	.208	1.199	2.049
	3	1	97.841	2.373	92.995	102.687
		2	3.774	.240	3.284	4.264
		3	1.576	.279	1.007	2.145
	4	1	96.850	2.466	91.814	101.885
		2	1.396	.140	1.111	1.681
		3	1.641	.274	1.081	2.201
	5	1	95.071	1.957	91.074	99.068
		2	1.070	.198	.666	1.474
		3	1.785	.297	1.180	2.391

Independent Validation of TERNZ/University of Waikato DS3 Driving Simulator for Research on Overtaking Lanes

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February 2003

Executive Summary

The research programme outlined in the following report was undertaken at the request of Transfund and involved a validation of the TERNZ/University of Waikato DS3 driving simulator with respect to the behaviour of motorists using overtaking lanes. Simulator data from the Human Factors of Overtaking Lane Design project (Transfund Project number PR3-0416) was compared to on-road measures taken from two overtaking lane sites on SH29 (the Kaimai route).

Traffic Planning Consultants Ltd undertook the research, with TERNZ providing assistance in the processing and interpretation of the simulation data.

A comparison of speed data showed that speeds seen in the laboratory conditions were very similar to those seen on the road (both absolute and relative behavioural validity was regularly achieved). There were some marked differences in lane selection behaviour, but these differences can most likely be explained through discrepancies between the on-road and simulated scenarios.

In general, results showed that the DS3 simulator is a valid and useful tool for the simulation of on-road treatments, with specific regard to overtaking lane research.

1. Background

This report outlines the validation testing of the DS3 Driving Simulator as requested by Transfund. The validation exercise is a requirement for the continuation of the current research into the impact of overtaking lane design on driver behaviour. The DS3 has been used for previous projects conducted by Transport Engineering Research NZ (TERNZ) and researchers at the University of Waikato investigating various traffic safety issues, including the impact of cell-phone use on driver attention, the effectiveness of rural/urban thresholds as speeding countermeasures, driver selection of speeds at curves, and eye-scanning behaviours while driving. Several of these projects have involved validation measures (Charlton et al. 2002, Alley 2000), but this is the first time that a validation specific to overtaking has been undertaken.

The validation work was undertaken by Traffic Planning Consultants Ltd (TPC), and involved the comparison of data from the Human Factors of Overtaking Lane Design (HFOLD) project recently completed by TERNZ (Transfund project number 0416), with data collected on-road by TPC. TERNZ provided assistance with the technical aspects of the validation including the processing and interpretation of data collected by the simulator. The following information was also made available to TPC to facilitate the validation:

- a review of driving simulator validation research literature
- the full specifications for the TERNZ/University of Waikato DS3 simulator
- a summary of the research methodology employed in the HFOLD project
- access to the complete data set from the HFOLD research project
- a summary of the findings from the HFOLD research project

2. The DS3 Driving Simulator

The DS3 driving simulator is one in a line of successively refined driving simulators developed at the University of Waikato in conjunction with TERNZ for the specific purpose of traffic safety research. The DS3 is a medium-fidelity driving simulator comprising a 21-inch CRT displaying coloured road scenes and steering wheel and foot pedal controls (see Figure 1). A typical driving scene from the simulator is shown in Figure 2.

RGDAS data (measured 3-dimensional road geometry) is used to specify the roadway. The roadway geometry is represented by means of a series of 4 x 4 metre vertices in which can be embedded even smaller undulations and bumps in the road surface. Signs, roadside furniture, and other objects such as buildings and trees are entered as digital images from a digital camera. In this way specific road sections can be recreated on the simulator.

Interactive non-linear multi-body simulations based on AUTOSIM vehicle models provide vehicle dynamics. Factors such as non-linear tyre behaviour, steering geometry, and suspension dynamics can be varied for light vehicles through to large articulated vehicles. Other vehicles can be entered in the driving scenario and controlled enabling overtaking situations to be created.

On-line measures that are typically collected include lane positioning, braking, speed maintenance, headway distances, stopping times, and occurrence of collisions.

Figure 1 Driving simulator configuration.

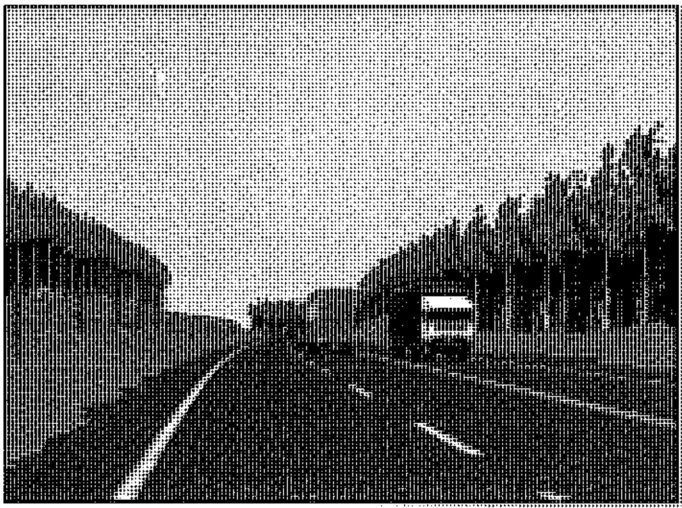

Figure 2 Typical simulated road scene.

3. Driving Simulators as a Research Tool

The use of air, marine, and road simulator technology has become increasingly prevalent for research in the area of transport safety (Gawron et al. 2002). Simulators provide a cost-effective means of implementing and testing novel traffic safety measures and road designs in a safe and controlled environment. Issues of validity must be addressed, however, to make the best use of their results. There are two facets of validity that need to be addressed with respect to driving simulator research: *physical* validity and *behavioural* validity (Godley et al. 2002).

Physical validity (often referred to as fidelity) refers to the ability of the driving simulator re-create a realistic driving environment (layout of controls and instruments and vehicle response to control inputs). Behavioural validity (often referred to as predictive validity) is concerned with the correspondence between behaviours exhibited in the driving simulator with those observed in on-road situations. It is behavioural validity that must be achieved before generalisations can be made to on-road situations.

Behavioural validity can be thought of in terms of *absolute* validity or *relative* validity. This is an important distinction with regard to driving simulator research. Figure 3 illustrates the difference between absolute and relative validity.

Panel A shows a situation where absolute validity is achieved in the control condition, but is violated in the treatment condition. Absolute validity requires that the numerical values match exactly when simulator data and on-road data are compared.

Panel B shows a situation where absolute validity is lacking in both the control and treatment conditions. However, the effect is of the same magnitude and in the same direction for both treatments. In this case we can say that relative validity has been achieved.

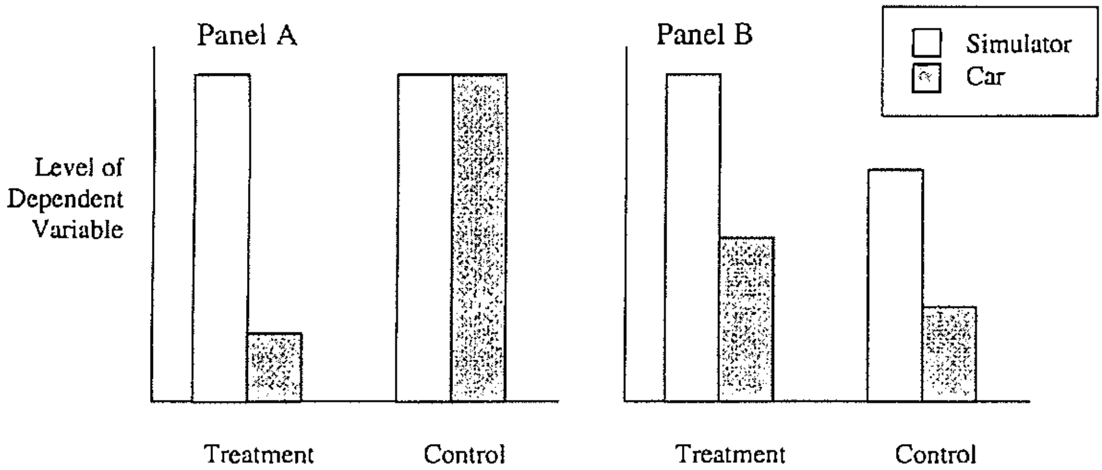

Figure 3 Hypothetical examples of absolute and relative validities.

(taken from Godley et al. (2002))

The general consensus in the literature is that:

> *...for a simulator to be a useful research tool, relative validity is necessary, but absolute validity is not essential. This is because research questions usually deal with matters relating to the effects of independent variables, with experiments investigating the difference between a control and treatment(s), rather than aiming to determine numerical measurements* (Godley et al. 2002).

4. Validation of the DS3 Driving Simulator

4.1 The HFOLD Methodology and Data Set

The simulator data that were analysed in this validation exercise was gathered during the Human Factors of Overtaking Lanes (HFOLD) project. The HFOLD project was conducted during 1999 and 2000 at the University of Waikato. The goal of the

HFOLD research was to improve overtaking safety through a better understanding of driver behaviour in a range of overtaking situations and road configurations. The Kaimai route between the Waikato and Tauranga (SH29 between Rapurapu Road and Omanawa Road) was recreated in the driving simulator.

The simulation was carried out with a mixture of cars, light trucks, and heavy trucks to represent a traffic volume of 14,000 passenger car units per day. Three-lane marking and sign treatments were applied to the road namely:

- the old New Zealand design (prior to July 2000);
- the current New Zealand standard (with diverge continuity line) that has recently been adopted;
- the Australian standard (with continuity lines at diverge and merge areas).

Thirty-one participants (17 women and 14 men), ranging in age from 19 to 71 years with driving experience ranging from 3 to 53 years (see Table 1) drove each of the six simulations across three experimental sessions. As Table 1 shows, the sample was generally representative of the New Zealand driving population.

Age (yrs)		**19-23**	**24-33**	**34-43**	**44-53**	**54-64**	**65+**
	#	7	5	8	6	4	1
	%	22.6	16.1	25.8	19.4	12.9	3.2
Driving Experience (yrs)		**3-5**	**6-15**	**16-25**	**26-35**	**36-45**	**45+**
	#	4	9	6	6	4	1
	%	13.3	30.0	20.0	20.0	13.3	3.3

Table 1 Distribution of participant ages and driving experience.

The experimental scenarios in the laboratory simulator were designed to ensure that drivers were interacting with other vehicles. As a result, drivers approached the diverge area behind several other vehicles. These vehicles were travelling at 80 km/h until 250 metres before the diverge point, then accelerated to approximately 95 km/h at the diverge area. The scenarios were also designed so that the majority of drivers would also encounter other vehicles at the merge area.

It should also be noted that, while the road itself was a reconstruction of SH29, the physical geometry of the five simulated overtaking lanes were modified to be representative of a range of merge geometries. As a result, the lanes that were simulated were not specific reconstructions of the passing lanes on that stretch of SH29. The lane merges were constructed so that one terminated on a straight, one on a blind curve, one of a left curve, one on a right curve, and one shortly after a crest.
To plan for a cost-effective validation it was decided to collect data (from tube counts and video) at two on-road sites for comparison to the simulator data (see the next section for details on the selection process for the on-road sites). Once the research team had selected the on-road passing lanes, the data from the simulated passing lanes that corresponded most closely to these two sites was extracted from the original HFOLD data set. For these two sites, the data pertaining to the current

(recently adopted) New Zealand treatments was extracted, and the on-road data was then collected for comparison.

4.2 The On-Site Methodology and Data Set

Detailed assessments were made of the passing lanes on SH29 between Hamilton and Tauranga to identify those with suitable operational and geometric characteristics. TERNZ staff undertook the initial appraisal, with the short-listed sites inspected jointly by TERNZ and TPC. The key criterion for site selection was that one of the sites terminated on a straight merge, while the other terminated on a blind merge. This criterion was derived from the HFOLD project, where the data showed that driver behaviour differed markedly as a result of this difference in merge geometry.

4.2.1 Selection & Location of Surveyed Sites

The two sites were selected to match (as closely as possible) two sites simulated in the laboratory experiment. Both sites were located on the SH29 route over the Kaimai Ranges. The straight merge was a 1 km-long passing lane commencing east of the Kaukumoutiti (Boulder) Stream bridge (with RP21/12.96 approximately midway along its length). The blind merge was a 2 km-long passing lane located close to the summit of the Kaimai Ranges, terminating a short distance east of Kaimai Primary School. Driving from Hamilton to Tauranga (eastwards) the driver would encounter the straight merge first and then the blind merge. The lanes were separated by a distance of approximately 1 kilometre.

In an effort to capture traffic patterns that were typical of "normal" weekday behaviour, the collection of the field data was timed to avoid school holidays and short weeks where the traffic flows may be affected by public holidays, times when road works were planned in the area, and particularly bad weather conditions.

It should be noted that the actual traffic volumes on the sections of road surveyed were in the order of 3600 vehicles per day compared to the simulated volume of 14,000 vehicles per day.

4.2.2 Data Collection Methodology

The collection of the traffic flow data required five traffic counters to be installed at each site (Figure 4). These were located:

1. Immediately upstream of the point where the single entry lane starts to diverge into two lanes (referred to as measurement location 1)
2. At the point where the marked lane line that defines the start of the overtaking lane commences (referred to as measurement location 2).
3. At a point 250 metres upstream of the terminating point of the two marked lanes (referred to as measurement location 3).
4. At the point where the marked lane line that defines the overtaking lane terminates (referred to as measurement location 4)

5. At a point the end of the merging area where all of the traffic is flowing in a single lane (referred to as measurement location 5)

The data collected at measurement locations 1 and 5 of each site were from a single lane of traffic. At measurement locations 2, 3, and 4 the counters were configured to record the traffic characteristics of each lane.

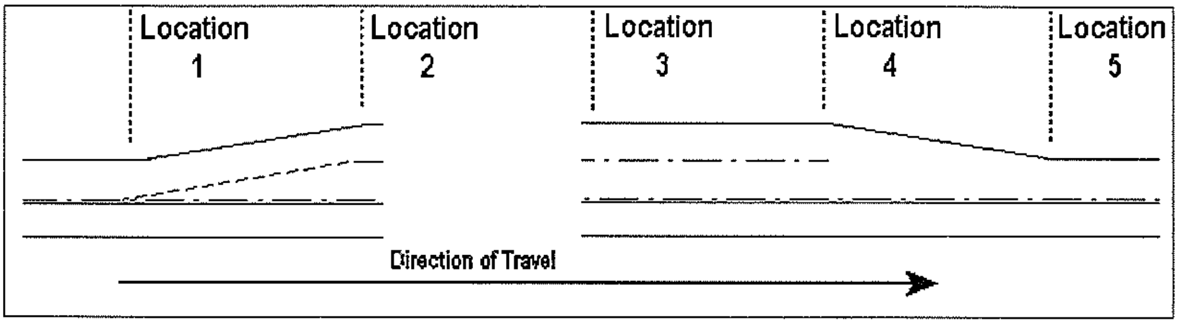

Figure 4 Measurement locations 1–5 used for the collection of traffic flow data.

The collection of the data was carried out by Scott Technical Ltd, a Hamilton-based company specialising in the supply and installation of traffic counting equipment. The traffic counters that were used were all Peek ADR1000 models. Unlike most traffic counters that store the data in user-defined categories or "bins", thus only providing totals for each group, the Peek counters stored all the information for every individual vehicle, including lane position, speed and time (dd/mm/yy, hh:mm:ss). This resulted in a considerable amount of information being recorded, allowing significantly more information to be extracted and processed out of the data (e.g. speed profiles (including percentiles) for specified time periods).

Given the time and operational constraints imposed by the temporary traffic control that had to be in place before the counters could be installed or lifted/relocated, the following timetable was adopted:

- Wednesday 4/9/02: install the counters in the appropriate measurement locations at the straight merge overtaking lane
- Thursday 5/9/02: record traffic flow and lane utilisation information
- Friday 6/9/02: remove counters from straight merge overtaking lane
- Monday 9/9/02: install the counters in the appropriate measurement locations at the blind merge overtaking lane
- Tuesday 10/9/02: record traffic flow and lane utilisation information
- Wednesday 11/9/02: remove counters from blind merge overtaking lane

To ensure that only the information for the days of interest was recorded at each site, the counters were programmed to commence counting at 00:00 (midnight) and terminate at 23:59:59, thus giving a full 24 hour count on the specified days.

To supplement this detailed information, continuous video filming was carried out of the merge area between 10.00am-12.00noon and 2.00pm-4.00pm on the Tuesday and Thursday. This footage was captured to aid researchers in the analysis of driver behaviour at the merge area.

4.2.3 Weather Conditions

The weather throughout the Thursday survey was not ideal with low cloud and steady rain falling most, if not all, of the day. On the following Tuesday the weather varied between (light to heavy) showers to fine and sunny periods. Overall, it is believed that the weather conditions did not significantly affect the behaviour of motorists using either passing lane.

4.2.4 Data Processing

The data collected from the counters was forwarded to Traffic Planning Consultants from Scott Technical in a number of Excel spreadsheets. A sample of the data provided is shown in Table 2:

		ARR	FLOW	STAT	VEHNO	SPD
501	"[START OF DATA]"					
05-Sep-02	00:01:55	1	+	FFFF	1	93
05-Sep-02	00:05:12	1	+	FFFF	2	102
05-Sep-02	00:05:50	1	+	FFFF	3	106
05-Sep-02	00:08:50	1	+	00FE	4	136
05-Sep-02	00:14:04	1	+	FFFF	5	56
05-Sep-02	00:14:19	1	+	FFFF	6	58
05-Sep-02	00:14:23	1	-	FFFF	7	124
05-Sep-02	00:14:27	1	+	FFFF	8	58
05-Sep-02	00:20:22	1	+	FFFF	9	96

Key:

"Arr": Detection of one vehicle
"Flow": Direction of travel (+/-)
"Stat": Vehicle code
"Spd": Speed of detected vehicle
"Vehno": Number of vehicles detected in that hour

Table 2 Dataset sample from on-site measures.

The processing of the supplied data showed up a range of speed values including extreme high and low measurements that occurred as a result of the vehicles not crossing the tubes at right angles. These errors, coupled with those that can arise from multi-axle vehicles, resulted in the raw data having to be filtered prior to detailed speed and lane utilisation assessments being made.

The thresholds that were set for this filtering were determined from a review of the data file and a subjective assessment as to what was reasonable and unreasonable.
For example, with respect to the upper speed threshold, the speed profile may have shown the expected patterns up to about 130 km/h. Beyond this point the number of observations may have quickly decreased before rapidly increasing, and being confined to reasonably narrow clusters that were generally in the order of 140-150 kph and 190 kph-210 kph. The thresholds that were adopted to filter the data files are shown in Table 3.

Location	Excessively high speed	Excessively low speed
Blind Merge #1	(filtering not necessary)	(filtering not necessary)
Blind Merge #2	Speeds more than 140km/h	Speeds less than 60km/h
Blind Merge #3	Speeds more than 135km/h	Speeds less than 26km/h
Blind Merge #4	Speeds more than 135km/h	Speeds less than 26km/h
Blind Merge #5	(filtering not necessary)	(filtering not necessary)
Western site #1	(filtering not necessary)	(filtering not necessary)
Western site #2	Speeds more than 135km/h	Speeds less than 26km/h
Western site #3	Speeds more than 135km/h	Speeds less than 30km/h
Western site #4	Speeds more than 135km/h	Speeds less than 30km/h
Western site #5	(filtering not necessary)	(filtering not necessary)

Table 3 Data filtering criteria.

4.3 Data Analysis

The validation focused on two key measures of overtaking (speed and lane selection), and compared these variables across the laboratory simulation and on-site situations. Prior to beginning statistical analyses, data from both experimental modes (on-site and simulator) were tested for normality using a Kolmogorov-Smirnov test. The results of this test showed that, while the simulator data was normally distributed, the on-site data was not. Therefore, non-parametric statistics were used for the following analyses.

4.3.1 Speed Selection – Analyses of Both Lanes

Figure 5 shows the speed profiles for both the on-site and simulator experimental modes in the straight merge scenario, whereas Figure 6 shows the speed profiles for both modes in the blind merge scenario. As can be seen, mean speeds were compared at five separate measurement locations[1]. A visual inspection of Figures 5 and 6 shows that, for both scenarios (blind merge and straight merge), there are marked differences in mean speeds between experimental modes at the diverge area (measurement locations 1 and 2). It is also apparent that, for both scenarios, speeds in the merge area (measurement locations 4 and 5) are similar for both experimental modes. It is also notable that at measurement location 3 in the blind merge scenario, speeds for the on-site mode are markedly slower than those in the simulation mode.

[1] Appendix A provides 85th percentile speeds for of the measurement locations, both for both lanes combined and for the left and right lanes separately.

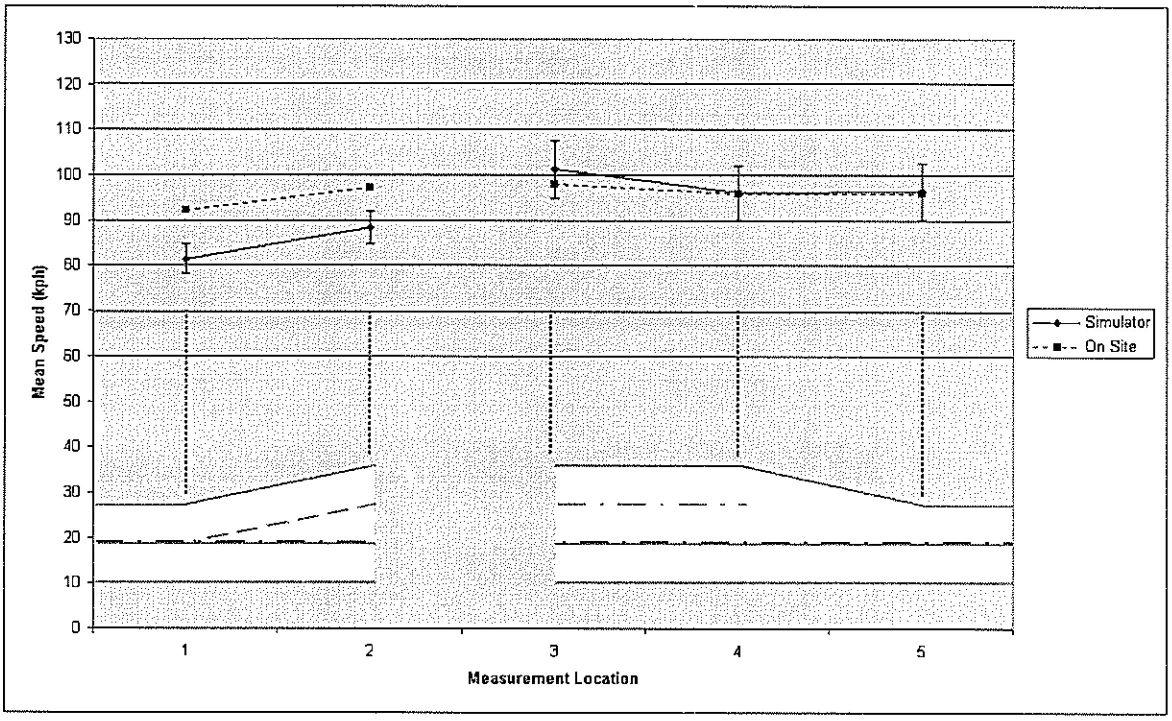

Figure 5 Mean speed – straight merge (across both lanes).

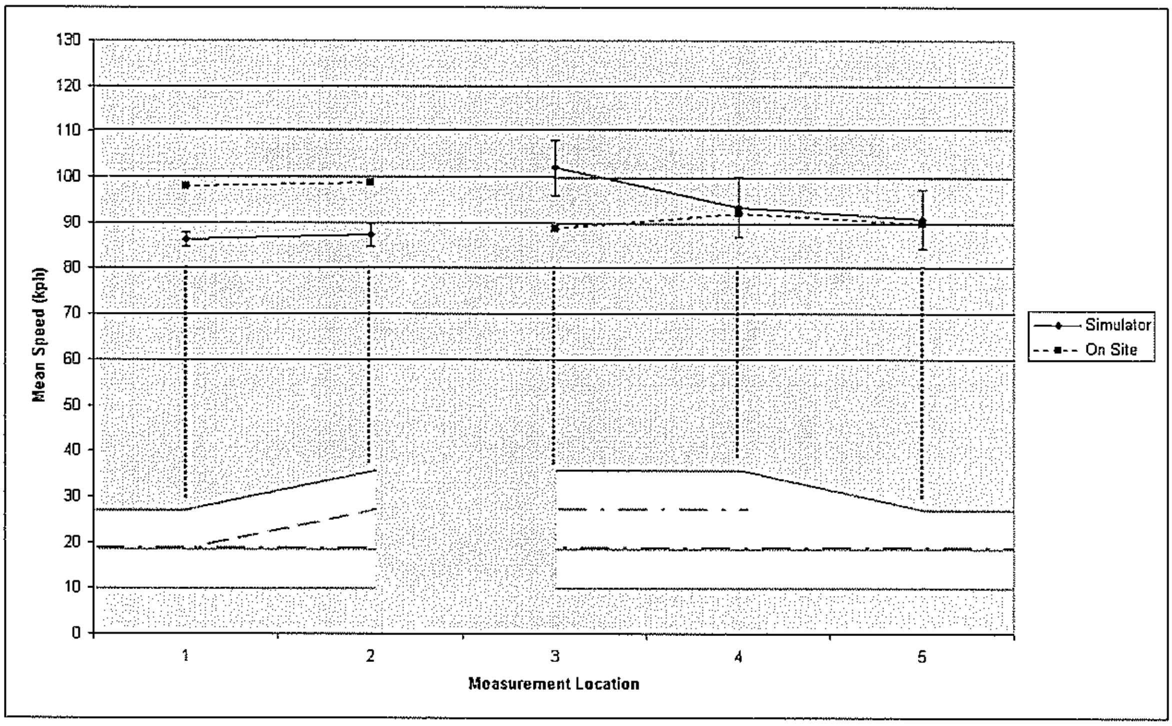

Figure 6 Mean speed – blind merge (across both lanes).

A series of Kruskal-Wallis tests were used to assess the statistical significance of the observed differences in speeds between experimental modes in the straight merge scenario (Figure 5). These analyses showed that at measurement locations 1 and 2 there were significant differences between mode speeds (measurement location 1, Kruskal Wallis = 48.601, df = 1, $p < 0.000$; measurement location 2, Kruskal Wallis = 18.594, df = 1, $p < 0.000$). However, there were no significant differences between mode speeds at measurement locations 3, 4, and 5 (measurement location 3, Kruskal Wallis = 1.036, df = 1, $p < 0.309$; measurement location 4, Kruskal Wallis = .328, df = 1, $p < 0.567$; measurement location 5, Kruskal Wallis = 0.019, df = 1, $p < 0.890$).

A series of Kruskal-Wallis tests were also used to assess the statistical significance of differences in speeds between experimental modes in the blind merge scenario (Figure 6). These analyses showed that at measurement locations 1, 2, and 3 there were significant differences between mode speeds (measurement location 1, Kruskal Wallis = 53.101, df = 1, $p < 0.000$; measurement location 2, Kruskal Wallis = 28.046, df = 1, $p < 0.000$; measurement location 3, Kruskal Wallis = 14.177, df = 1, $p < 0.000$). However, there were no significant differences between the mode speeds at measurement locations 4, and 5 (measurement location 4, Kruskal Wallis = 0.000, df = 1, $p < 0.987$, measurement location 5, Kruskal Wallis = 0.187, df = 1, $p < 0.666$).

The difference in on site and simulator mode speeds for both scenarios at measurement locations 1 and 2 most likely resulted from the differences between the traffic situations developed for the simulator and situations typically encountered on the road. As previously stated, all of the drivers (in both driving simulator scenarios) approached the diverge area platooned behind vehicles travelling at 80 km/h, a situation that might only occur occasionally on site. As a result, drivers in the simulator mode were generally travelling slower at measurement location 1 than those in the on-site mode. One should note while drivers in the simulator mode are travelling slower, the acceleration profile from measurement location 1 to measurement location 2 show similar trends for both experimental modes, and that this trend is consistent across both the straight and blind merge scenarios.

The differences between on-site and simulator mode speeds at measurement location 3 in the blind merge scenario (Figure 6) may be an artefact of the differences in road geometry between modes. In the simulator mode the blind merge occurred on a level stretch of road, whereas the on-site blind merge occurred on a hill.When one compares speed profiles for both the blind and straight merge scenarios (i.e. both Figures 5 and 6), it is apparent that it is only the on-site data at measurement location 3 in the blind merge scenario that does not fit with the general speed trends.

The similarity in speeds at measurement locations 4 and 5 for both scenarios is notable. In fact, it appears that not only has relative behavioural validity been achieved, but absolute behavioural validity also. The data is trending in the same direction and the numerical values are similar (the greatest discrepancy between speeds is 3.8 km/h at measurement location 4 on the blind merge). This is particularly relevant to the current research as the experiments to be conducted focus on the design of the merge area.

4.3.2 Speed Selection – Analyses of Left and Right Lanes

The data in the above graphs was averaged across both lanes within each scenario. It is expected that, due to the nature of passing lanes, speeds could be markedly different between the inside (right-most) and outside (left-most) lanes. As a result, the data was also analysed with respect to the individual lanes. With reference to the analyses below, the reader should note that only measurement locations 2, 3, and 4 provide data for two lanes, the statistical analyses for measurement locations 1 and 5 have been described above, so will not be repeated below.

Figures 7 and 8 show the speed profiles for vehicles travelling in the right-hand lane at the straight and blind merge scenarios. Both scenarios produced significant differences between on site and simulator mode speeds at measurement locations 1 and 2 (measurement location 2, straight merge scenario, Kruskal Wallis = 22.746, df = 1, $p < 0.000$; measurement location 2, blind merge scenario, Kruskal Wallis = 20.700, df = 1, $p < 0.000$).

For measurement locations 3, 4, and 5 in the straight merge scenario (Figure 7), the mode speeds were not significantly different (measurement location 3, Kruskal Wallis = 0.522, df = 1, $p < 0.470$; measurement location 4, Kruskal Wallis = 2.469, df = 1, $p < 0.116$).

Similarly, there were no significant differences between mode speeds at measurement locations 4 and 5 in the blind merge scenario (Figure 8), (measurement location 4, Kruskal Wallis = 0.096, df = 1, $p < 0.757$). However, analysis showed that mode speeds at measurement location 3 in the blind merge scenario were significantly different (Kruskal Wallis = 10.895, df = 1, $p < 0.001$). Once again, this is only the data point that does not conform to any obvious trend (one would assume that this is again because the on site geometry contained a hill at this point and the simulator geometry did not).

Figures 9 and 10 (p.129) show the speed profiles of vehicles travelling in the left lane for the straight merge scenario (Figure 9) and the blind merge scenario (Figure 10). In the straight merge scenario there are significant differences between mode speeds at measurement locations 1, 2, and 3 (measurement location 2, Kruskal Wallis = 16.385, df = 1, $p < 0.000$; measurement location 3, Kruskal Wallis = 9.370, df = 1, $p < 0.002$). There is no significant difference between mode speeds at locations 4 and 5 (measurement location 4, Kruskal Wallis = 3.438, df = 1, $p < 0.064$).

In the blind merge scenario (Figure 10) there were significant differences between mode speeds at measurement locations 1 and 2 (measurement location 2, Kruskal Wallis = 19.434, df = 1, $p < 0.000$). There were no significant differences in mode speed at measurement locations 3[2], 4, and 5 (measurement location 3, Kruskal Wallis = 3.344, df = 1, $p < 0.067$; measurement location 4, Kruskal Wallis = 0.06, df = 1, $p < 0.940$).

2 Note that while there is no significant difference between the driving simulator and on-site speed measure at location 3, the error bars in Figure 10 do not cross. This is due to the non-normal distribution of the on-site data, the large discrepancies in standard error between the two samples, and the differences in sample size.

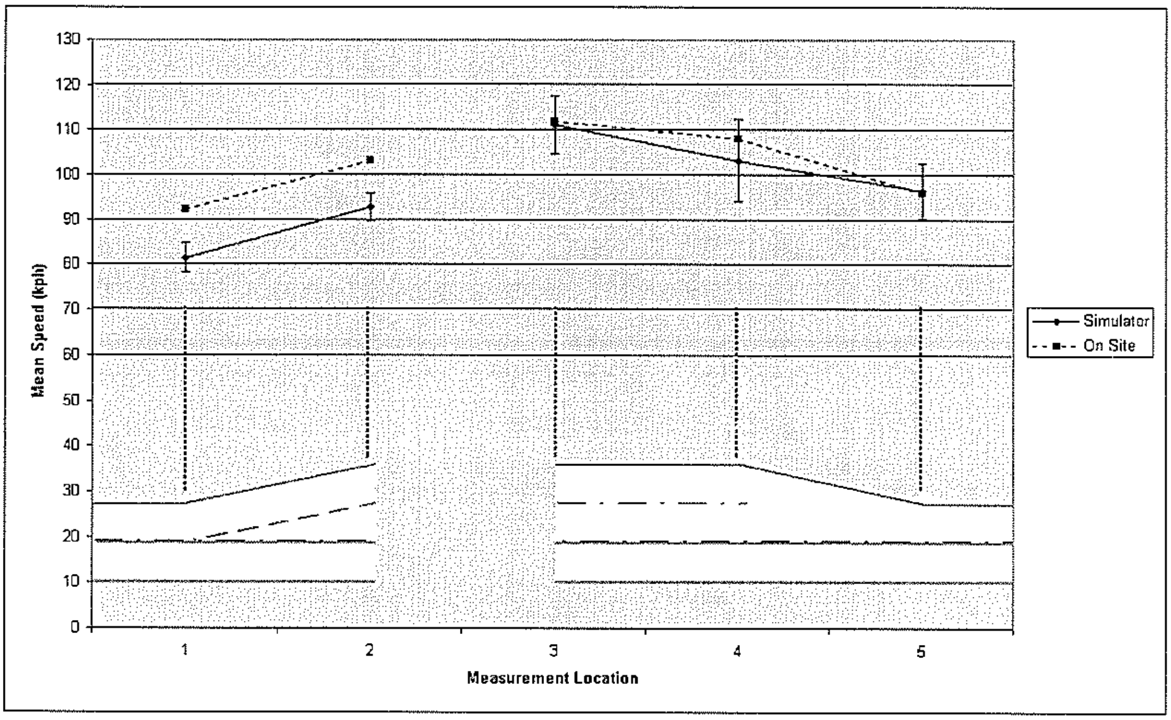

Figure 7 Mean speed – straight merge (right lane).

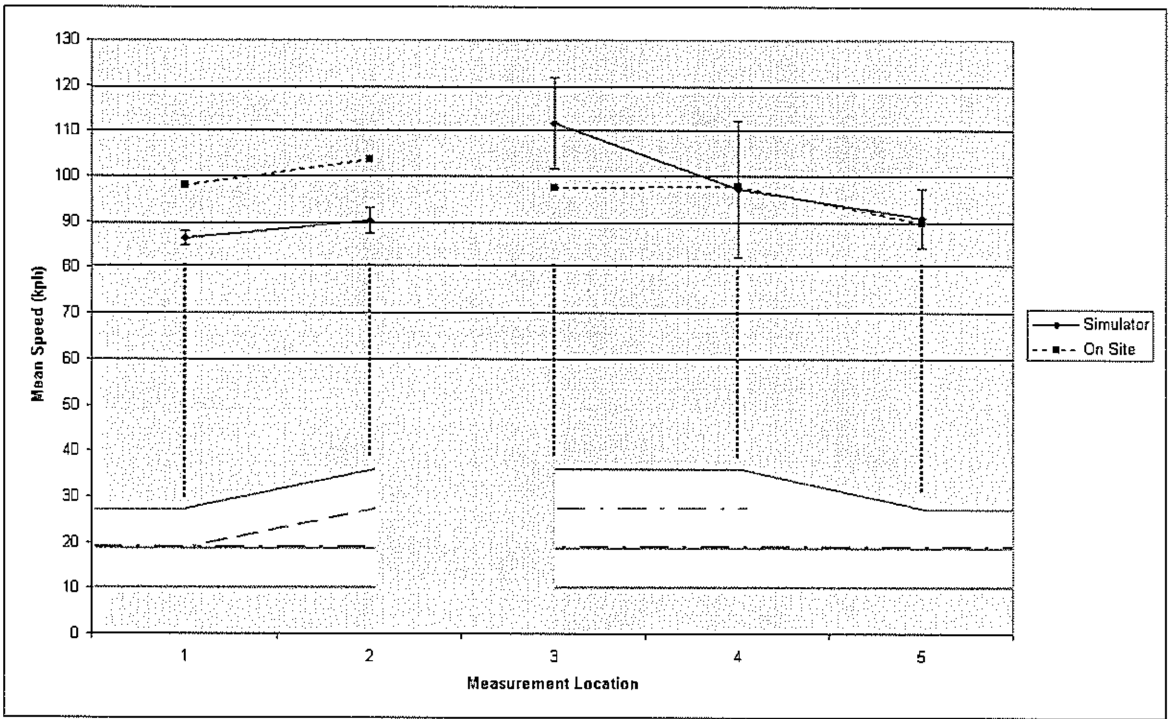

Figure 8 Average speeds in right lane – blind merge.

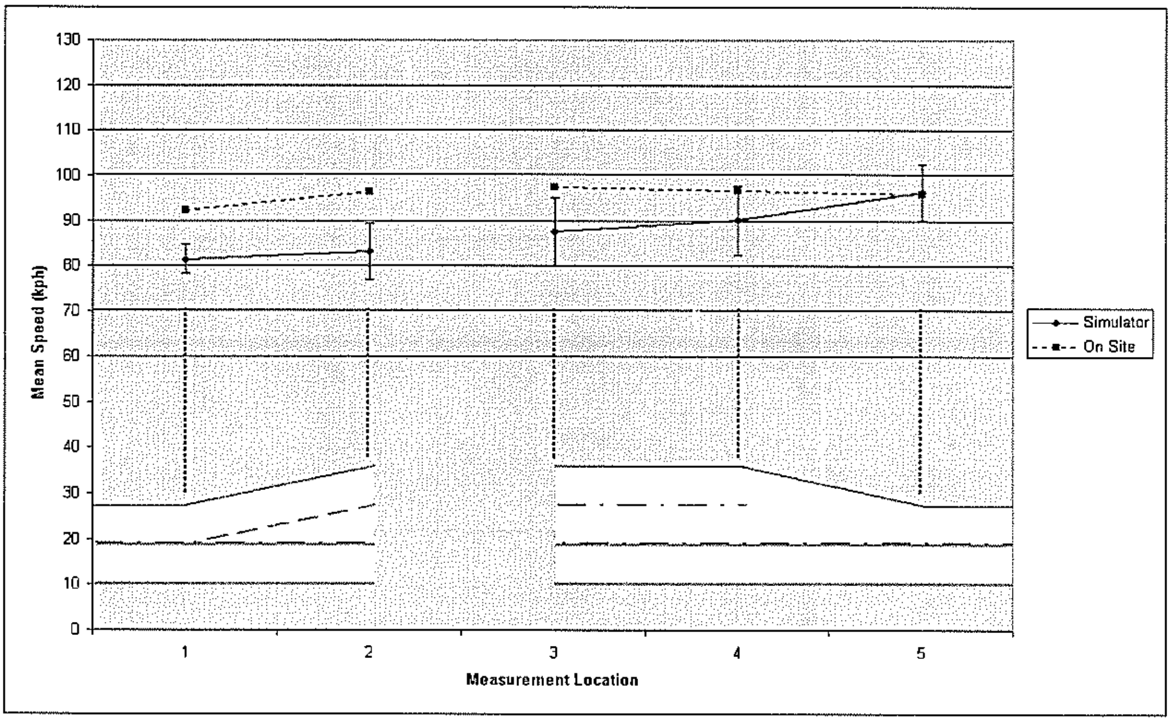

Figure 9 Average speeds in left lane – straight merge.

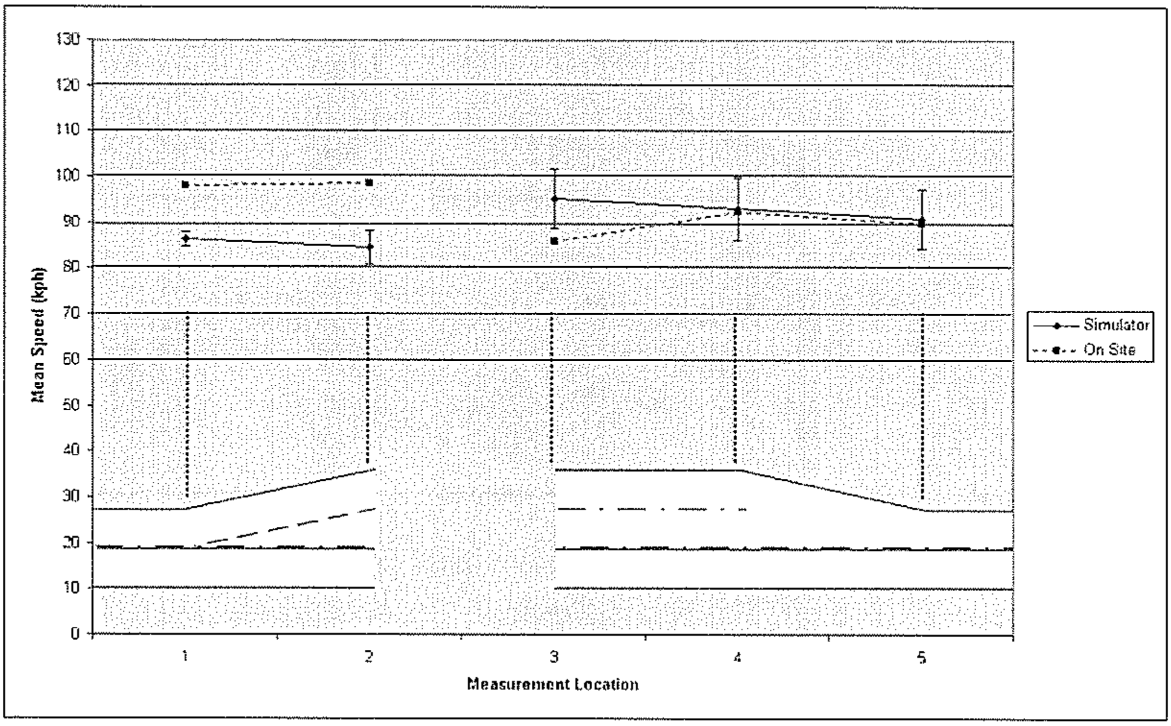

Figure 10 Average speeds for left lane – blind merge.

The data points at measurement location 3 for the straight merge scenario stand out as been inconsistent with all of the previous trends (i.e. Figures 5 through to 8). In all other instances there has been no significant difference in modes speed at this measurement location. It is possible that this difference is, once again, an artefact of a traffic situation in the simulation. In the simulation, every driver that selected the left lane within 1 km of the merge area in the straight merge scenario would have encountered slow moving vehicles in that lane, whereas this would not necessarily be the case for drivers in the on-site situation.

4.3.3 Lane Selection

While the speed information is an important part of this assessment, driver's lane selection behaviour in each mode was also of interest. Table 4 shows the data for lane selection for the straight and blind merge scenarios. The data were taken from measurement location 2, immediately after the diverge. This analysis was of particular interest for the HFOLD research as the effectiveness of the diverge continuity line (as deployed in the current NZ standard) was a defining feature of the HFOLD study.

The first comparison that was undertaken was between the simulator data set and the full on-road data set. As can be seen, there were large discrepancies between on site and simulator modes with approximately 50% of drivers in the simulator mode choosing the right lane in both scenarios and only approximately 10% choosing the right lane in the on site mode.

Diverge Type	**Data Type**	**Lane Selection**	
		Left (%)	*Right (%)*
Blind	*Simulator*	51.61	48.39
	On-Site – All vehicles	87.90	12.1
	On-Site – Platooned (4 sec)	76.39	23.61
	On-Site – Platooned (3 sec)	73.37	26.63
	On-Site – Platooned (2 sec)	67.55	32.45
Straight	*Simulator*	45.16	54.84
	On-Site – All vehicles	91.80	8.2
	On-Site – Platooned (4 sec)	73.50	26.5
	On-Site – Platooned (3 sec)	71.24	28.76
	On-Site – Platooned (2 sec)	66.63	33.37

Table 4 Percentage of vehicles in each lane at the diverge.

The research group was concerned that these marked differences may have been artefacts of the traffic situation presented to drivers in the simulated scenarios (i.e. all of the simulator drivers approached the diverge area platooned behind vehicles travelling at 80 kph). In order to create more comparable data sets, the on-site data was progressively filtered to extract only those vehicles that were in a similar traffic situation to those in the simulator scenarios. It was felt that the most effective means of doing this was to identify vehicles that were in a platooned traffic situation, and to analyse the lane selection behaviour of these vehicles only. The dataset was filtered to extract all vehicles that were following within 2, 3, or 4 seconds of another.

Table 4 shows that, as the data is progressively filtered, the differences between the lane selection behaviour in each of the modes lessen. When lane selection behaviour is analysed for vehicles travelling within 2 seconds of another vehicle, 67.55% of drivers in the blind merge scenario and 66.63% of drivers in the straight merge scenario have selected the left lane. These results are more encouraging, especially when we take into account several mitigating factors that may still impact on the equivalence of the data sets for the two-second filter:

- The measures in the simulator mode were gathered from a single simulated vehicle type (2 litre sports model), whereas the data from the on-site mode were gathered from various vehicle types (including a substantial proportion of heavy vehicles).
- All drivers in the simulator mode were at the very back of a platoon of vehicles, whereas the platooned vehicles in the on-road situation could be at any position in the platoon (thus affecting decisions to pass).

4.4 Conclusion

The validation of the simulation data has been carried out in a detailed manner with speed profiles and lane selection assessed at key points through the overtaking lane.

With respect to the *speed-related aspects* of the verification, it has been concluded that the simulation has extremely good relative behavioural validity at the merge area both across both lanes and when the left and right lanes were analysed separately. This is of particular interest to the current study as it suggests that the driving simulator will be particularly suited to the current research into overtaking lanes, which focuses on issues at the merge area. However, some differences were noted at the diverge area. These differences were consistent both across lanes and when the left and right lanes were analysed separately. The research team believes they are largely due to the influence of the design of the simulator scenarios, for example, the platooned vehicles, their slow speeds, and the differences between the on site and simulator traffic volumes. Despite this there is still good relative behaviour validity at the diverge in that the relative speed increase from measurement location 1 to location 2 is similar between experimental modes.

Although good behavioural validity was achieved with the speed data, the results of the *lane selection analysis* are somewhat inconclusive due to the differences in the on-site and simulator data sets. The comparison of the two full data sets highlights marked differences in lane selection behaviour between the simulated and on-road scenarios. When the on-road data set was filtered in an attempt to produce more comparable data sets, the differences between results were greatly reduced.

Although there are some marked differences in lane selection behaviour, overall, this verification has concluded that the results of the simulation are very similar to those seen on the road. On this basis it is believed that the DS3 simulator is a valid and useful tool for the simulation of on-road treatments, with specific regard to overtaking lane research, provided the operational parameters of the simulation reflect reasonably well the characteristics of any real-life situation that is being modelled. In the event that hypothetical situations are being modelled, it is believed that the results will be applicable to similar real-life situations.

With specific regard to the current study of overtaking lanes, the simulator data provided a good match with the on-site data collected at the merge. Because the data for the current study will be collected at the merge area it is concluded that the simulator provides a valid tool for the current experiment.

Appendix A 85th Percentile Speeds for all Measures

Site details			Site 1	Site 2	Site 3	Site 4	Site 5
Both lanes	*Blind Merge*	*Simulator*	90.44	93.79	117.11	109.87	107.50
		On-Site	108.00	113.00	105.00	104.00	102.00
	Straight Merge	*Simulator*	88.99	98.13	115.93	110.19	109.54
		On-Site	106.00	108.00	110.00	108.00	106.00
Right Lane	*Blind Merge*	*Simulator*	90.44	91.16	111.36	108.66	107.50
		On-Site	108.00	110.00	104.00	104.00	102.00
	Straight Merge	*Simulator*	88.99	94.14	101.58	109.22	109.54
		On-Site	106.00	108.00	108.00	106.00	106.00
Left Lane	*Blind Merge*	*Simulator*	90.44	95.23	134.56	120.15	107.50
		On-Site	108.00	117.00	110.00	110.00	102.00
	Straight Merge	*Simulator*	88.99	98.45	121.82	120.15	109.54
		On-Site	106.00	113.00	123.00	120.00	106.00

Appendix B Validation of the TERNZ/University of Waikato DS9 Driving Simulator: Verification of Accuracy for Overtaking Lane Research

Introduction

This appendix outlines the validation testing of the DS9 Driving Simulator undertaken by TERNZ researchers as part of the 'Impact of Overtaking Lane Design on Driver Behaviour' research programme (Transfund Project Number PR3-0712; Luther et al. 2004). The DS9 simulator was used in this project to gather data on driver behaviour at merge areas. In the course of this project the straight merge that was measured during on-site measures (described in this report) was re-created in the simulator as one of a battery of eight sites to be tested[3]. Drivers' speed and lane position when driving in the simulator was recorded at five separate positions in the merge area (Figure 11). Of these five positions three are in comparable positions to those selected for the on-site measures; the first of these (M2 in Figure 11) corresponds to measurement location 3 (see Figure 4); the second (M3) corresponds to measurement location 4, and; lastly, M4 corresponds to measurement location 5. Note that M2 (250 m before the merge) and measurement location 3 (200 m before the merge) differ by 50 m. In order to conduct a validation of the DS9 driving simulator, drivers' speeds and lane position were compared at positions M2/ measurement location 3, M3/ measurement location 4, M4/ measurement location 5.

The data points at measurement location 3 for the straight merge scenario stand out as been inconsistent with all of the previous trends (i.e. Figures 5 through to 8). In all other instances there has been no significant difference in modes speed at this measurement location. It is possible that this difference is, once again, an artefact of a traffic situation in the simulation. In the simulation, every driver that selected the left lane within 1 km of the merge area in the straight merge scenario would have encountered slow moving vehicles in that lane, whereas this would not necessarily be the case for drivers in the on-site situation.

Lane Selection

While the speed information is an important part of this assessment, driver's lane selection behaviour in each mode was also of interest. Table 4 shows the data for lane selection for the straight and blind merge scenarios. The data were taken from measurement location 2, immediately after the diverge. This analysis was of particular interest for the HFOLD research as the effectiveness of the diverge continuity line (as deployed in the current New Zealand standard) was a defining feature of the HFOLD study.

The first comparison that was undertaken was between the simulator data set and the full on-road data set. As can be seen, there were large discrepancies between on site and simulator modes with approximately 50% of drivers in the simulator mode choosing the right lane in both scenarios and only approximately 10% choosing the right lane in the on site mode.

[3] The reader is directed to the research report cited (Luther et al. 2004) for a full description of the research methodology.

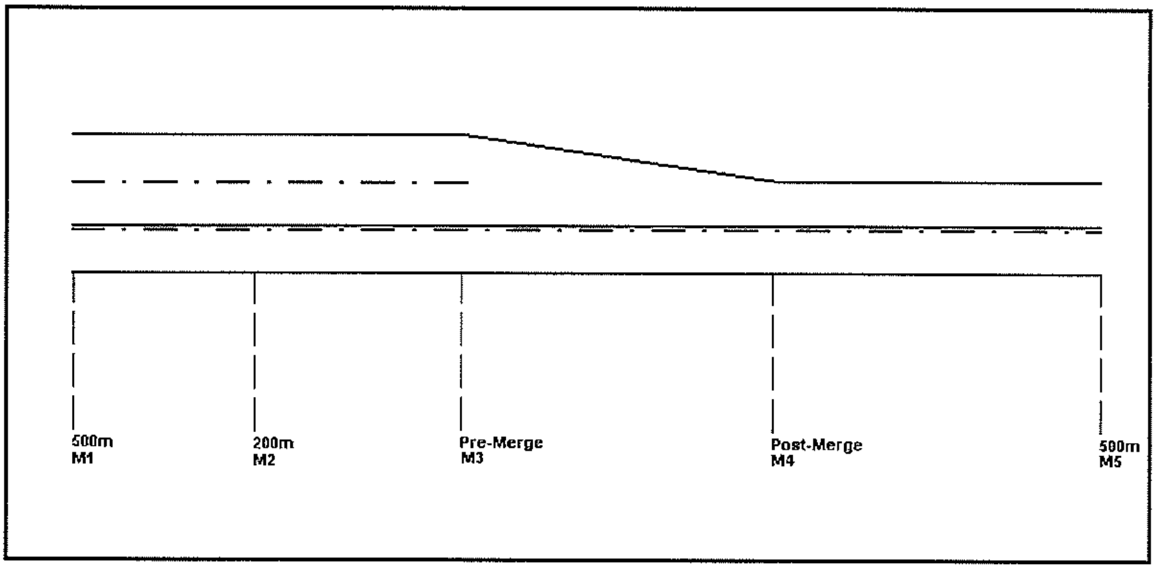

Figure 11 Measurement locations in DS9 Simulator experiment.

Speed Selection

Figures 12, 13, and 14 show the average speeds for both the simulator data and the on-site data. Figure 12 shows the speeds combined across both the left and right lanes of the overtaking lane. As can be seen, the drivers in the simulator condition are travelling faster at all three measurement positions (by 7.88 kph at measurement location 3, 8.39 kph at measurement location 4, and 3.49 kph at measurement location 5). The two data sets exhibit reasonably good relative validity; with the only difference being a more noticeable decrease in speeds between measurement locations 4 and 5 for the simulator condition. It is notable that, at measurement location 5, absolute validity has been achieved; with the mean of the on-site population falling within two standard errors of the simulator population mean.

Figure 13 shows the speeds of the vehicles that were positioned in the left lane at the point of the measurement location. It should be noted that measurement location 5 has not been included in this graph, as it is not possible for vehicles to be in the left lane at this stage as only one lane exists at this point. Once again, drivers in the simulator condition exhibit higher speeds (by 7.12 kph at measurement position 3 and by 3.1 km/h at measurement position 4), but both datasets are trending in the same direction, exhibiting reasonably good relative validity.

Figure 14 shows the speeds of the vehicles that were positioned in the right lane at the point of the measurement location. As can be seen, absolute validity is achieved at measurement locations 3 and 4 (with the mean of the on-site population falling within two standard errors of the simulator population mean), and that relative validity is achieved between measurement locations 4 and 5 (with both datasets trending in the same direction).

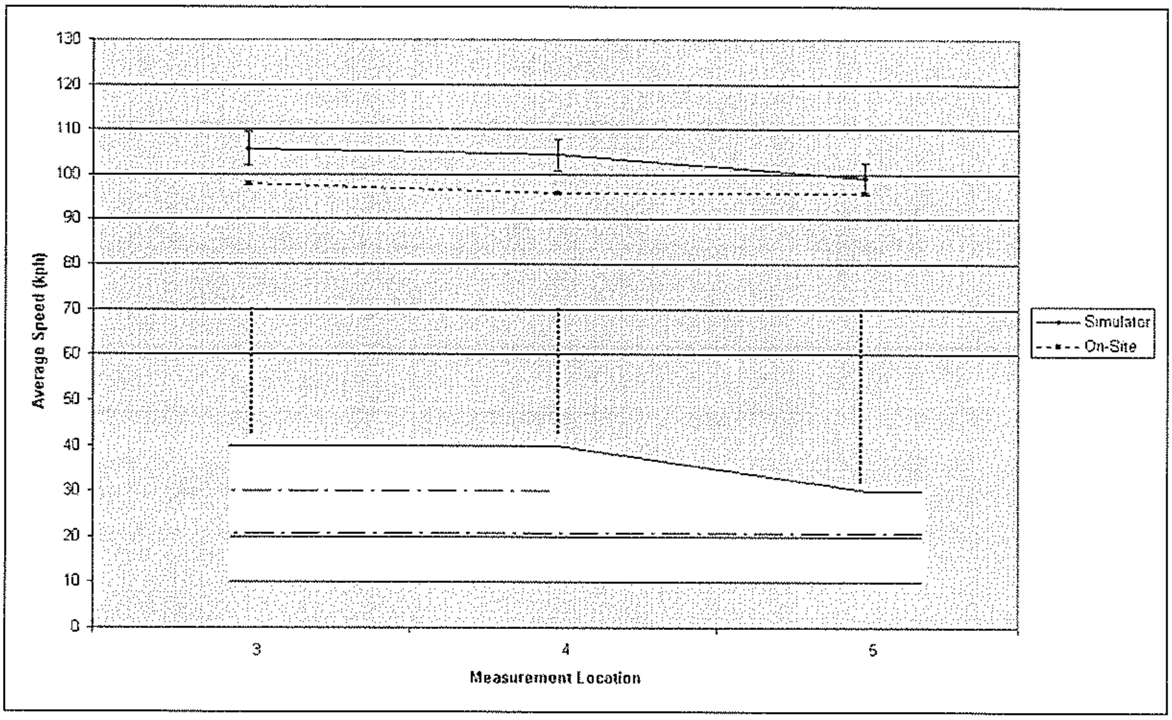

Figure 12 Average speed across both lanes: simulator v on-site measures.

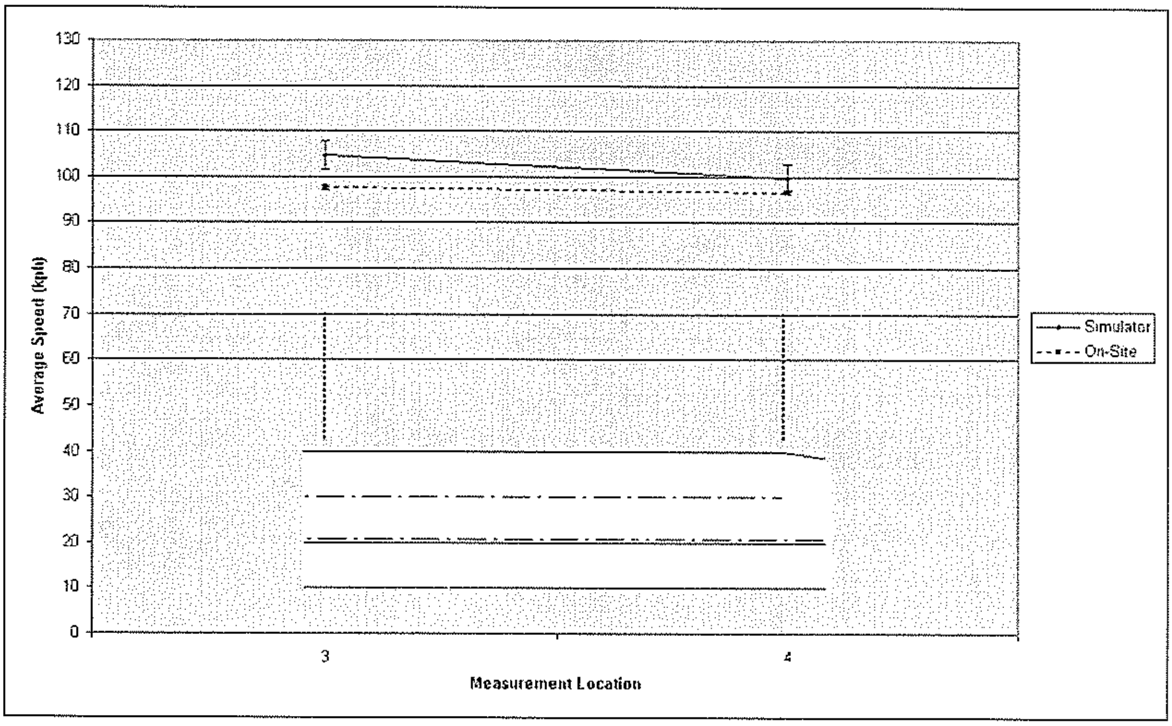

Figure 13 Average speed in left lane only: simulator v on-site measures.

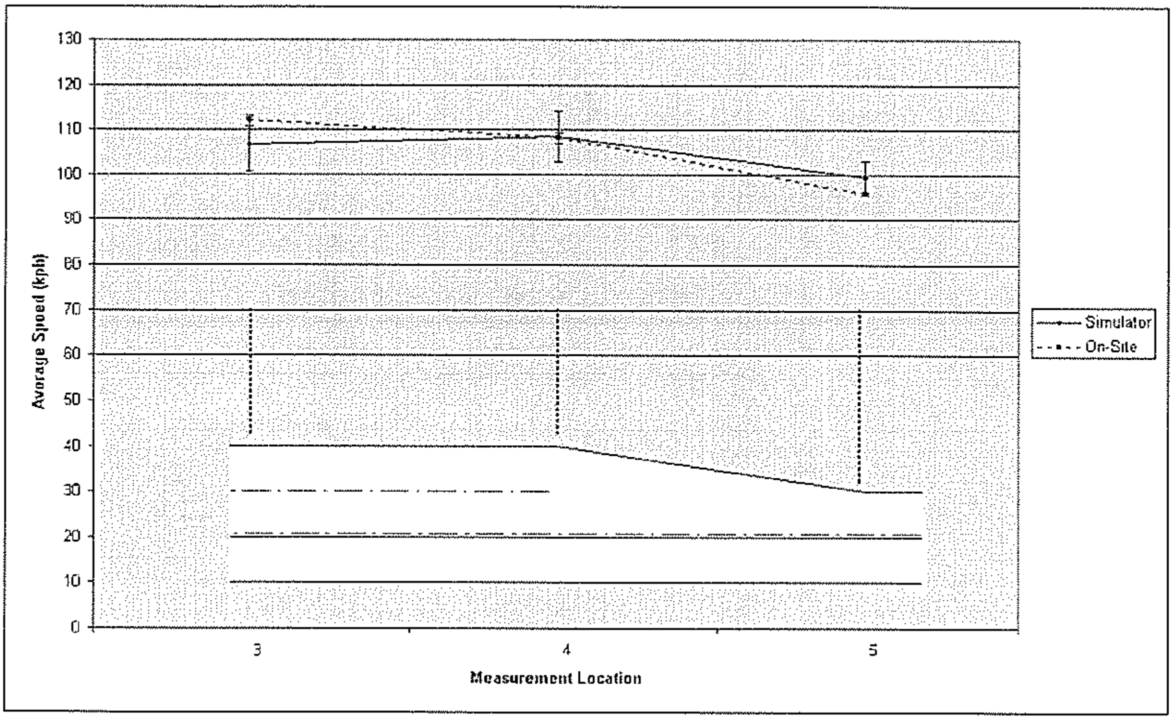

Figure 14 Average speed in right lane only: simulator v on-site measures.

Lane Selection

Table 5 shows the percentage of vehicles in each lane at measurement positions 3 and 4 for both the simulator and on-site conditions. As can be seen, there are notable differences in lane selection between conditions at both measurement points with an overwhelming majority of on-site drivers selecting the left lane, compared to a reasonably even split in the simulator.

Measurement Location		**3**	**4**
Simulator	*Left Lane*	42%	48%
	Right Lane	58%	52%
On-Site	*Left Lane*	89%	88%
	Right Lane	11%	12%

Table 5 Percentage of vehicles in each lane.

This result is very similar to that seen in the DS3 lane selection analysis and, once again, is most likely an artefact of the experimental design. In the simulator experiment involving the DS9, scenarios were developed to encourage interaction with other vehicles, making it more likely that participants would be in the right lane (engaging in overtaking manoeuvres).

Summary

The validation of the DS9 simulation data has been carried out in a detailed manner with speed profiles and lane selection assessed at key points through the overtaking lane.
With respect to the speed-related aspects of the verification, it has been concluded that in most instances the simulation has either good relative or absolute behavioural validity. Although good behavioural validity was achieved with the speed data, the results of the lane selection analysis are somewhat inconclusive due to the differences in the on-site and simulator data sets. The comparison of the two datasets highlights marked differences in lane selection behaviour between the simulated and on-road scenarios. As with the DS3 validation, it is suggested that these differences most likely occur as a result of experimental artefacts.

Although there are some marked differences in lane selection behaviour, overall, this verification has concluded that the results of the simulation are very similar to those seen on the road.

On the basis of the above analysis, it is suggested that the DS9 simulator is a valid and useful tool for the simulation of on-road treatments, with specific regard to overtaking lane research, provided the operational parameters of the simulation reflect reasonably well the characteristics of any real-life situation that is being modelled.

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