SEARCH NEW ZEALAND LIMITED

Human Factors of Overtaking Lane Design

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The Human Factors of Overtaking Lane Design

This project was aimed at improving overtaking lane design through a better understanding of driver behaviour during overtaking. Overtaking lane designs and road geometries representative of those found on State Highways were re-created in the driving simulator used for this research. Results showed that when the diverge and merge areas are clearly visible, there is little difference between the three different road marking and signage treatments investigated. However there were significant differences when these areas are not clearly visible. Both the new NZ and the Australian treatments worked well in the diverge area, but there were safety issues with the Australian treatment in the merge area. Further research is proposed to investigate the effect of factors such as merge length, merge placement, alternative marking schemes and sign placement.

Introduction

This paper describes a Transfund research project undertaken by Transport Engineering Research New Zealand (TERNZ) investigating the human factors of driver behaviour in a range of overtaking situations and road configurations with the view of improving safety. The research explored the effects of several types of overtaking lane and signage treatments in the safety and controlled environment of a state-of-the-art driving simulator.

The term 'Human Factors' refers to a specific methodological approach to research problems. As the name suggests, this approach focuses on the human within any given operating system (anything from a vehicle to a nuclear power station) or environment. In this case we are looking at the human operator within a specific system (the vehicle) within a specific environment (overtaking lanes) with the view to designing the environment to optimise human behaviour and therefore reduce accidents.

The current research was undertaken in response to concerns raised by Transit NZ staff about safety aspects of overtaking lanes. The research focuses on overtaking because road deaths involving overtaking have been rapidly increasing with 31, 42, and 45 deaths for the 12 months to January 1997, 1998 and 1999 respectively (a 45% increase over the 3 years). Deaths involving overtaking now account for 10% of all road deaths[1]. 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, (May, 1991).[2]

For the research described here, a medium-fidelity driving simulator at the University of Waikato was used to explore the effectiveness of several alternative designs for overtaking lane treatments across a range of road geometries. The DS3 simulator is a state of the art medium-fidelity desktop driving simulator developed by researchers, programmers, and technicians at the University of Waikato for use in driving related research. Issues that have been investigated using this technology include the impact of cell-phone use on driver attention, the effects of rural threshold treatments in reducing drivers' speeds, the effects of workload on driver attention, the effect of other traffic on speed selection, and the effect of traffic speeds on following distances. The investigation of the human factors of overtaking lane design is the most ambitious project to be conducted using the DS3 technology thus far.

[1] Road Deaths, Land Transport Safety Authority official road fatality statistics.
[2] May A.D. Traffic Performance and Design of Passing Lanes, TRB Record 1303, 1991.

Major upgrades were instituted in order to effectively conduct the research described. All of the graphic components of the simulator were upgraded to enhance the simulation quality and realism. More simulated vehicles were introduced in order to represent traffic volumes and compositions for the roads chosen for this study. Software was developed that allowed RGDAS data to be introduced into the simulator, converting actual road geometries into simulated road geometry. All of these additions have helped to make the DS3 simulator more realistic and effective than ever before (see Figure 1).

Figure 1. Examples of a DS3 Simulation

Methodology

After consultation with a Steering Committee comprised of industry experts and end-users it was decided that three design standards would be examined. The three treatments were as follows: Treatment 1 – the Current New Zealand Standard (prior to July 2000); Treatment 2 – the New New Zealand Standard (post July 2000); Treatment 3 – the Australian Standard (see Appendix A).

It was also decided that SH29 (between Rapurapu Road and Omanawa Road) had a fair representation of the typical road geometries present in which overtaking lanes occur. Based on the comments received from the Peer Reviewers, and subsequent discussion of the reviews by the Steering Committee members, a final selection of six overtaking sites along SH29 was made. The selected sites were then inspected, measured, photographed and the entire route videotaped from a moving vehicle. Road geometry data was obtained from the RGDAS database and traffic volume and speed data were obtained from both on-site observations and Transit New Zealand.

The resulting information was used to create two simulations of SH29, one eastbound and one westbound. Each simulation contained three overtaking sites in the direction of travel with the other three shown in the opposing lanes. The six overtaking lanes selected for the analysis (see in Table 1), were selected to represent a variety of lengths and geometries with special emphasis placed on the diversity of the merge areas.

Table 1. Simulated overtaking lanes

Site East 1	A 4 kilometre overtaking lane with a 120 metre diverge taper, incorporating several turns, terminating on a gentle left turn just past the crest of a hill with an 88 metre merge taper.
Site East 2	A 1 kilometre overtaking lane with a 60 metre diverge taper terminating on a left turn with a 60 metre merge taper.
Site SVB	A 200 metre slow vehicle bay with a 32 metre diverge taper and a 64 metre merge taper.
Site West 3	A 3 kilometre overtaking lane with a 60 metre diverge taper, incorporating several turns, terminating on a straight with an 88 metre merge taper.
Site West 4	A 1.5 kilometre overtaking lane with an 80 metre diverge taper terminating on a gentle right turn with a 60 metre merge taper.
Site West 5	A 1.5 kilometre overtaking lane with an 80 metre diverge taper terminating on a blind left turn with a 120 metre merge taper.

A within-subjects experimental design was employed, with each participant driving six simulations across three experimental sessions. During the first session each participant was given a practice track to drive until they felt comfortable operating the simulator. Participants then drove the eastbound and westbound routes for one of the three treatments (Current, New, or Australian). The order of presentation of treatment condition and east/westbound legs was counterbalanced across all participants. During the second session, the participant drove the east/west pair for another treatment condition, and the final east/west pair during the third experimental session. Traffic volumes were set at 14000 passenger car units per day, with a mix of cars, vans, light trucks, and heavy trucks. Overtaking scenarios were developed so that the participants were encouraged to interact with the other vehicles in the simulation. Subsequent sessions for each participant were scheduled between one and three days apart.

A total of 35 participants were tested (not including the four used to pilot the experimental procedure); 19 women and 16 men ranging in age from 19 to 80 years. Four participants withdrew from the experiment either due to discomfort during the first experimental session (difficulties seeing the computer screen or motion sickness) or declined to continue past the first session due to the time commitment required. The remaining 31 participants, 17 women and 14 men, ranged in age from 19 to 71 years (average age 38.19) and ranged in driving experience from 3 to 53 years (average 20.58 years). A total of approximately 70 hours of driving data were collected in the simulator and retained for analysis.

Results

Simulator data and research findings

Averages for lane position, vehicle speed, and following distance were calculated for each treatment condition across the 31 participants. Measures were taken at eight metre intervals through the diverge and merge sections of each overtaking lane, and at 120 metre intervals for the 500 metres leading up to and following each diverge and merge section. Each overtaking lane was divided into 6 sections for analysis, as shown in Figure 2. Results were averaged across each of the six sections for each measurement criteria (see Appendix B) and then compared for statistically significant differences.

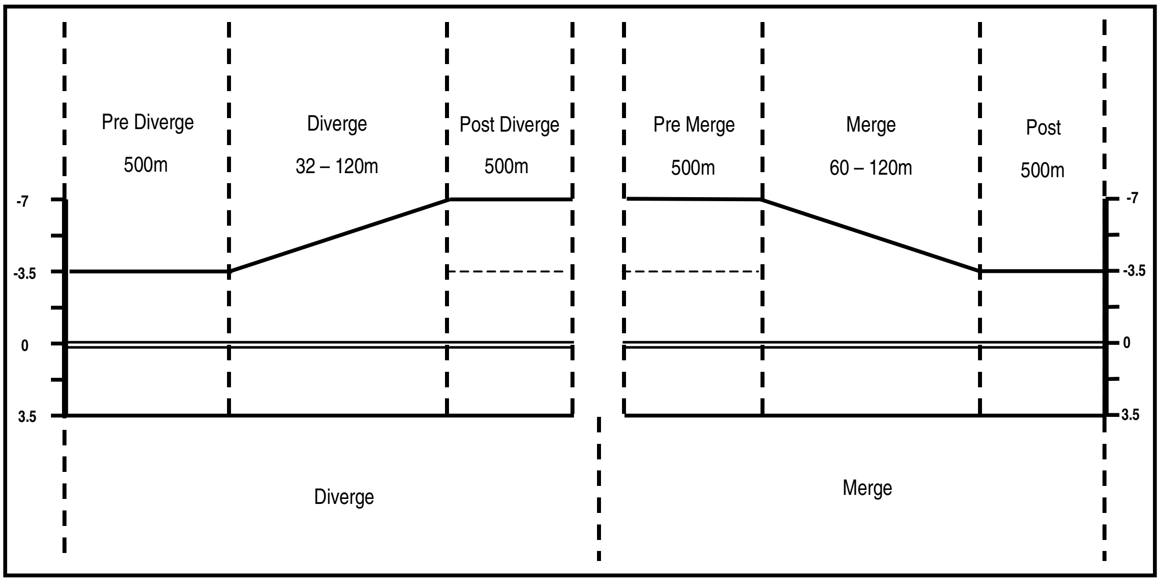

Figure 2. Sectioning of overtaking lanes for analysis.

A multivariate analysis of variance (MANOVA) calculated on these averages indicated highly significant differences across all of the measurement criteria[3], suggesting that the six overtaking lanes selected Steering Committee represented reliably different overtaking situations.

[3] $F_{(20, 580)} = 22.70$, $p < .001$

When averages were compared across the entirety of all three lane treatments it was found that there was a significant difference for participants lane positions[4]. There was also a significant interaction between participant gender and the overtaking lane section[5], arising from slower speeds and longer following distances maintained by female participants during the pre-merge and merge phases.

Next, each of the overtaking sites was examined individually for differences between each of the three treatments in participants' lane position, speeds, and following distances. The overriding trend at the diverge area was that the Australian treatment tended to move drivers to the left sooner than the other two treatments (see the lateral displacement results in the diverge section of Appendix B). This effect can be seen at all of the diverges, suggesting that the alternate signage (placement of an advance warning at 300m and the use of the word 'Overtaking' instead of 'Passing') in the Australian standard had differential affect, as compared to the New NZ standard (which also employed continuity line at the diverge taper – see Appendix A). There was a difference in speeds for site East 2, with the Australian treatment producing significantly higher speeds than the other two treatments (Current, 79.03 kph; New NZ, 79.37 kph, and; Australian, 84.07 kph) in the pre-diverge section. Generally speaking, the Australian treatment produced higher speeds at the diverge section.

There were also appreciable trends observed across the merge section for the three treatments. The results show that, generally, the Australian treatment encouraged participants to merge to the left during the 500 metre pre-merge section, and this effect is possibly due to the alternate signage in the merge section for the Australian treatment (see Appendix A). When the number of vehicles passed at site East 2 were analysed it was shown that 2.97 vehicles (mode and median also equal to 3) were passed in Current NZ treatment. In comparison, participants overtook an average of only 2.68 vehicles while driving the New NZ treatment, and 2.42 while driving the Australian treatment. It is reasonable to assume that the fact that participants merge sooner in the Australian treatment resulted in less vehicles being passed. The Australian treatment also produced lower speeds at the merge than the other two treatments. When site East 2 was analysed more extensively it was apparent that the lower speeds were due in part to the fact that participants merged left in the pre-diverge section, this also resulted in closer following distances.

It was also apparent that at sites East 2, West 3, and West 5, while driving the New NZ treatment participants stayed further left in the merge taper than in the other two treatments, indicating that the drivers were making use of the hatched runout provided for in this treatment (see Appendix A).

Relationship with road design

To see how these results related to engineering road design the following aspects were examined at the diverge and merge areas for each treatment: taper lengths, speed differential, position of the merge area, signage and sign position, and road markings. Several factors that may have affected lane positions and following distances for each treatment were considered. Firstly, the taper lengths at the diverge and merge areas used in the simulation were checked against design guidelines as shown below in Table 2.

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[4] $F_{(2,58)} = 5.61$, $p < .01$
[5] $F_{(20,580)} = 2.03$, $p < .01$

Table 2. Comparison of diverge and merge lengths to standards and guidelines

	Simulation Diverge Tapers	Simulation Merge Tapers
Transit NZ 2001 Policy	100% of recommended lengths (Recommended: 70 – 100m)	40% – 75% of recommended lengths (Recommended: 115 – 160m)
Australian Guidelines	89% of recommended lengths	40% - 60% of recommended lengths (Recommended: 150m)
AustRoads Formula	*	30% - 50% of recommended lengths

(It should be noted here that the taper lengths used in the simulation were derived from the actual tapers at the sites chosen)

A consistency check of speeds over the merge area was undertaken to ascertain the effect of the short taper lengths on merge manoeuvres (for this analysis it was decided that the merge area required specific attention because of the higher potential for overtaking problems).

From an engineering perspective a roadway can be considered as a combination of successive geometric elements. For example, a merge section of an overtaking lane can be deconstructed into pre-merge, merge, and post-merge phases. On roads designed for speeds of 100kph or more, drivers will adopt a relatively uniform speed of travel across the successive geometric elements. A driver will expect to be able to maintain a high travel speed, and the design must be able to accommodate this. Provided the standards are in keeping with driver expectancies, a safe and adequate alignment will result. As such, design standards should strive to produce homogenous speeds across individual elements, providing a higher level of safety and convenience to all road users. Normally, design speeds should not differ by more than about 10kph on successive geometric elements, (AustRoads, 1993)[6]. A variance of greater than 10kph speed between design elements on a road has the potential to create safety problems.

The consistency check of average speed and average 85%tile speed throughout the merge manoeuvre (including pre-merge, merge, and post-merge) showed that there were significant speed variations for the sites with restricted visibility and difficult topography at the merge area. The average speed differential at the “benign” merge situations (Site West 3 – Straight and Site West 4 – Right) was less than 10 kilometre per hour (kph), however for the more “challenging” merge situations, that is those with restricted forward visibility (Site East 1 – Post crest, Site East 2 – Left, Site West 5 – Blind, and the Slow Vehicle Bay), a change in speed greater than 10kph occurred. A consistency check for the average 85%tile speed (or design speed) showed the speed differential to be similar to the differential of average speeds.

As suggested, the significant difference in average 85%tile speeds over the different phases of merging indicates the greater potential for safety problems. Speed differentials were within the acceptable range for design consistency for all treatments at sites where there was good forward visibility, while the more “challenging” sites showed speed differentials greater than that recommended for safe road design, as detailed above (while it is recognised that the volume of traffic on overtaking lanes influences average

[6] Rural Road Design, Guide to the Geometric Design of Rural Roads, AustRoads, Sydney, 1993

speeds, for the sites tested the traffic volumes used in the simulation was consistent for each scenario).

In looking at the signage and sign position at the diverge areas, it was interesting to note the difference in driver behaviour between the New NZ treatment and the Australian treatment, where drivers consistently moved to the left faster with the Australian treatment. In both cases the road markings were the same with the continuity line directing vehicles to the left side of the road, however the sign message wording differed between the two treatments, as did the sign location. Although these differences were not considered to be great, they may have contributed to the differing test results, however further research is needed to establish this possibility.

The Australian and New NZ diverge markings with the continuity line directing traffic to the left, were much more efficient in moving traffic over sooner as compared to the Current NZ design. The earlier move to the left enabled following vehicles waiting to overtake to do so more quickly, and this was highlighted with the Australian design where vehicles moved left the soonest, a greater number of vehicles were passed in the earlier stages of the overtaking lane.

At the merge areas, the current NZ and New NZ design markings (discontinued lane lines and no priority given to drivers in either lane) appeared to result in a more efficient and safer driving situation than the Australian design (where priority was given to the driver in the overtaking lane). Headway distances were much reduced with the Australian design, and speeds were lower throughout the merging manoeuvre. This may have been caused by driver unfamiliarity with the lane continuity line, greater advance warning of the merge area, or the fact that the drivers were merging earlier. Although more vehicles were passed in the earlier stages of the Australian standard, fewer vehicles were overtaken through the entire overtaking lane.

Recommendations and implications for future research

There were two primary recommendations derived from the findings of this research. Firstly, it was recommended that, where possible, the full length of the diverge and merge tapers should be clearly visible over their entire length and at least 200m from their start. Secondly, that the road marking and signage introduced at the diverge areas after July 2000 be fully implemented. The view was taken that the New NZ treatment provided a reasonable trade-off between safety and efficiency.

It was the opinion of the research team, Steering Committee and the peer reviewers that further research was required, specifically investigating the effects of merge length, merge placement (within the existing road geometry), and alternative marking schemes and sign placement. It is considered to be premature to put forward recommendations for merge area treatments given the number of questions regarding taper lengths and location the research raised.

Conclusion

In conclusion, it can be seen that at sites with long approaches and high forward visibility the driving behaviour was approximately equivalent under the three treatments (e.g., sites West 3 and West 4), and a reasonable level of safety was maintained. At sites with shorter approaches, or where visibility was somewhat more restricted due to the topography or road geometry, there were dangerous inconsistencies in speed maintenance.

The diverge continuity line used in the New NZ and Australian treatments did move more drivers to the left. The Australian treatment, however, achieved this effect sooner and at higher vehicle speeds than the New NZ treatment. This advantage is presumably attributable to the different approach signage, as that was the only difference between these two treatments. Irrespective of the greater movement of drivers to the left lane, the higher speeds associated with the Australian treatment apparently resulted in greater rates of overtaking in the early stages of the overtaking lane.

Towards the end of the lane, the presence of the early warning and merge continuity line in the Australian treatment had the effect of slowing drivers and reducing the overall overtaking rates. The hatched runout at the end of the New NZ treatment was used by the participants, as reflected in their delayed move to the right lane in the merge section.

So, under the most benign conditions there were no differential effects of the three treatments. With poorer visibility or more taxing road geometry, the drivers relied more heavily on the road markings and signage and the effects of the treatments become more pronounced, and the sensitivity to the more "challenging" situations was borne out by the greater speed differential between merge area sections at these sites.

Acknowledgements

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The Steering group consisted of:
- Mr Bob Gibson, Senior Traffic Engineer, LTSA Head Office
- Mr Ian Cox, Regional Highways Engineer, Transit New Zealand
- Mr Murray Noone, PROJENZ, Land Transport Consultant

The peer reviewers were:
- Dr Denis Davis, Traffic and Design Manager, Transit NZ Head Office
- Mr J.P. Edgar, Manager Safer Roads, LTSA Head Office
- Mr Jos Vroegop, Traffic Planning Consultants Ltd
- Dr Barry Parsonson, Road Safety Consultant

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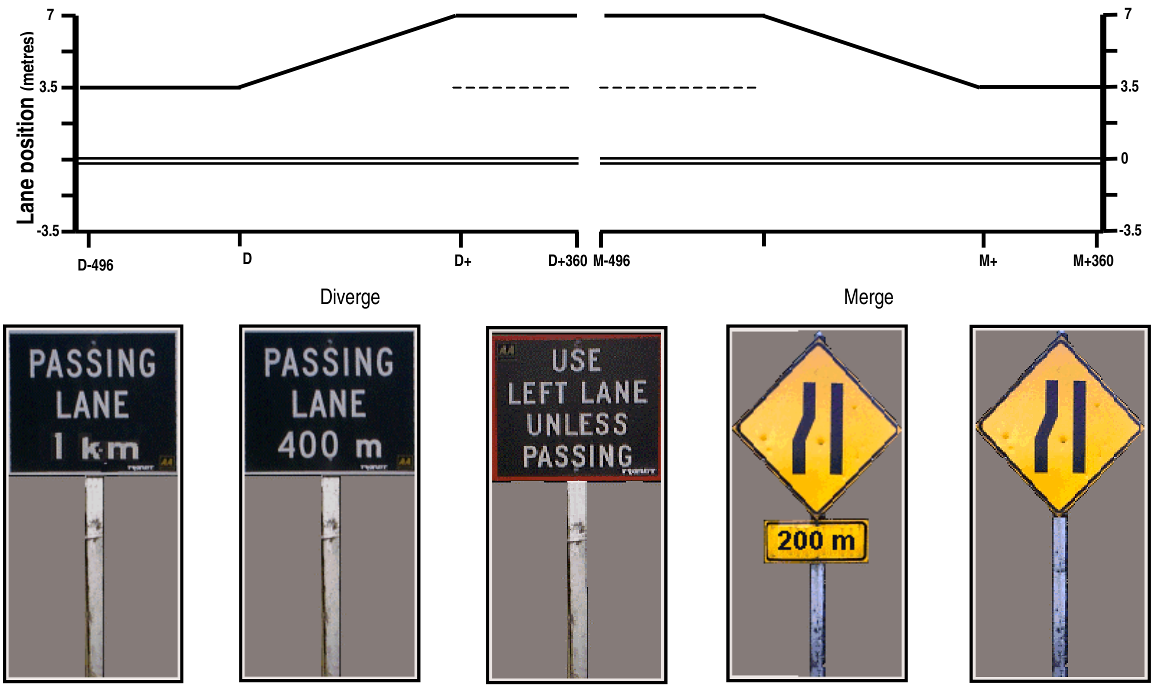
We are particularly grateful for the time and effort provided by the drivers that participated. They all provided their time freely and willingly in the interest of improving road safety.

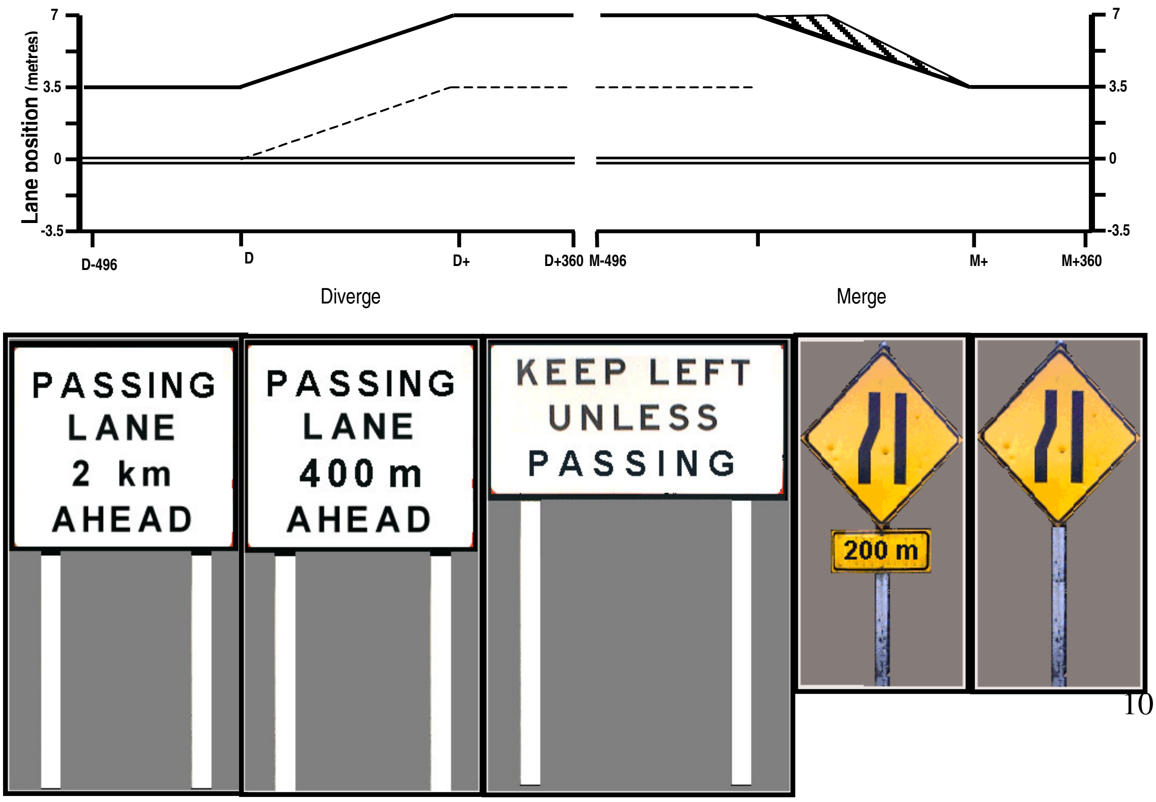
Appendices

Appendix A – Three overtaking lane treatments

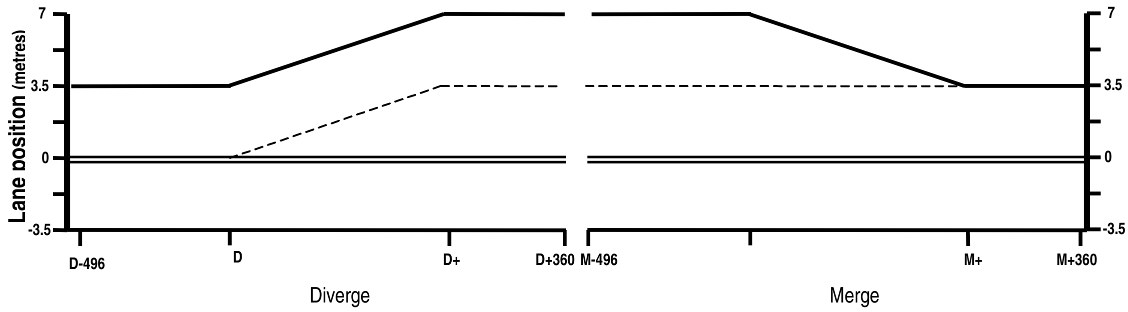
Current NZ



New NZ

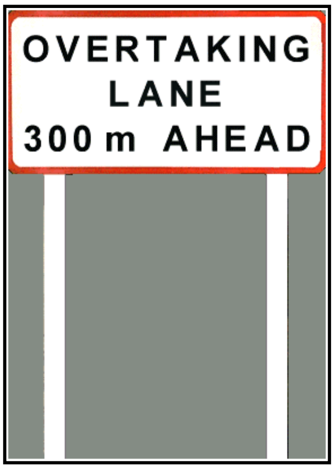


Australian



Lane position (metres)
7
3.5
0
-3.5
D-496
D
D+
D+360
M-496
M+
M+360
Diverge
Merge

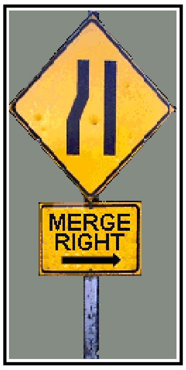
OVERTAKING
LANE
2km AHEAD



OVERTAKING
LANE
300 m AHEAD

KEEP LEFT
UNLESS
OVERTAKING

500 m



MERGE
RIGHT

Appendix B – Averages for all sites.

	SPEED					
	Site East 1					
	Pre Diverge	Diverge	Post Diverge	Pre Merge	Merge	Post Merge
Current	80.53	88.58	100.39	76.29	80.58	89.15
NZ New	82.58	85.81	99.93	76.28	82.86	91.82
Australian	82.16	86.11	100.58	75.67	78.57	88.53
	Site East 2					
	Pre Diverge	Diverge	Post Diverge	Pre Merge	Merge	Post Merge
Current	79.03	78.90	89.33	89.33	74.76	80.03
NZ New	79.37	81.74	89.04	89.04	74.30	81.17
Australian	84.07	83.81	87.39	87.39	69.81	79.09
	Site West 3					
	Pre Diverge	Diverge	Post Diverge	Pre Merge	Merge	Post Merge
Current	83.12	88.65	99.84	103.19	97.08	99.51
NZ New	83.57	86.08	97.25	101.21	95.88	99.74
Australian	81.75	89.58	98.10	98.74	94.65	98.72
	Site West 4					
	Pre Diverge	Diverge	Post Diverge	Pre Merge	Merge	Post Merge
Current	81.65	87.53	98.49	103.51	99.18	100.35
NZ New	83.19	84.52	97.23	105.15	101.38	101.19
Australian	85.71	88.84	99.13	95.35	92.92	95.30
	Site West 5					
	Pre Diverge	Diverge	Post Diverge	Pre Merge	Merge	Post Merge
Current	79.07	87.47	90.36	101.66	92.06	87.97
NZ New	78.00	86.84	88.82	100.89	92.60	88.60
Australian	78.87	86.41	90.10	97.15	89.56	90.48
	Site SVB					
	Pre Diverge	Diverge	Post Diverge	Pre Merge	Merge	Post Merge
Current	61.43	69.67	73.50	73.50	64.11	74.20
NZ New	62.24	72.66	77.93	77.93	66.43	75.82
Australian	61.85	72.67	76.95	76.95	66.19	76.48

	LATERAL DISPLACEMENT					
	Site East 1					
	Pre Diverge	Diverge	Post Diverge	Pre Merge	Merge	Post Merge
Current	-1.91	-1.95	-2.05	-3.21	-2.29	-1.87
NZ New	-1.87	-2.19	-2.33	-3.39	-2.44	-1.97
Australian	-1.85	-2.43	-2.30	-3.68	-2.56	-1.95
	Site East 2					
	Pre Diverge	Diverge	Post Diverge	Pre Merge	Merge	Post Merge
Current	-1.83	-2.29	-2.63	-2.63	-1.95	-1.86
NZ New	-1.89	-2.29	-2.81	-2.81	-2.25	-1.88
Australian	-1.98	-2.73	-3.02	-3.02	-1.89	-1.89
	Site West 3					
	Pre Diverge	Diverge	Post Diverge	Pre Merge	Merge	Post Merge
Current	-1.88	-2.50	-2.56	-2.92	-2.50	-1.71
NZ New	-1.81	-2.68	-3.09	-3.28	-2.68	-1.66
Australian	-1.86	-2.81	-3.12	-3.50	-2.54	-1.75
	Site West 4					
	Pre Diverge	Diverge	Post Diverge	Pre Merge	Merge	Post Merge
Current	-1.67	-2.76	-3.08	-3.08	-2.96	-2.10
NZ New	-1.73	-2.68	-3.10	-3.26	-2.90	-2.02
Australian	-1.79	-3.03	-3.29	-3.83	-3.00	-2.11
	Site West 5					
	Pre Diverge	Diverge	Post Diverge	Pre Merge	Merge	Post Merge
Current	-1.70	-2.61	-2.12	-2.91	-2.84	-1.75
NZ New	-1.67	-2.69	-2.37	-3.46	-3.44	-1.77
Australian	-1.68	-2.79	-2.47	-3.13	-2.65	-1.74
	Site SVB					
	Pre Diverge	Diverge	Post Diverge	Pre Merge	Merge	Post Merge
Current	-1.84	-1.34	-1.34	-1.34	-1.67	-1.96
NZ New	-1.91	-1.39	-1.28	-1.28	-1.64	-1.95
Australian	-1.90	-1.45	-1.41	-1.41	-1.67	-1.96

NB – Lateral displacement is measured in metres from the centre line, with negative values to the left of the centre line and positive values right of the centre line.