Improving safety for people who cycle on rural roads
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An important note for the reader

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Abbreviations and acronyms

AADT	average annual daily traffic
CAS	Crash Analysis System
DfT	Department for Transport (UK)
km/h	kilometres per hour
OECD	Organisation for Economic Co-operation and Development
ONRC	One Network Road Classification
RCA	road controlling authority
SWOV	The Dutch Institute for Road Safety Research
TCD	Traffic Control Devices (Committee)
Transport Agency	New Zealand Transport Agency
UK	United Kingdom
US/USA	United States of America

Contents

Executive summary 7
Abstract 10
1 Introduction 11
1.1 Key research questions/project objectives 11
1.2 Key project stages 11
2 Review of literature and practice 13
2.1 Introduction 13
2.2 Context 13
2.3 CAS analysis 14
2.3.1 Methodology 14
2.3.2 Crash statistics 14
2.3.3 Vehicle movements 17
2.3.4 Contributing factors 19
2.3.5 Geographic locations 19
2.3.6 Key findings drawn from CAS analysis 22
2.4 Road treatments and measures 22
2.4.1 Safer speeds for shared rural road space 23
2.4.2 Speed reducing measures 24
2.4.3 Case studies 27
2.5 Measures of safety effectiveness 34
2.6 Process for selecting trial treatments, measures and site location 36
2.6.1 Design consideration rationale 36
2.6.2 Process for selecting performance measures 39
2.6.3 Process for selection of possible trial locations 40
3 Method 41
3.1 On-road trials 41
3.1.1 Experimental treatment design layout 41
3.1.2 Treatment implementation 44
3.1.3 Road treatment performance measures 48
3.1.4 Location 50
3.1.5 Participants 50
3.1.6 On-road trial participant procedure 51
3.2 Data analysis 51
4 Results 52
4.1 Bicycle instrumentation results 52
4.1.1 Instrumentation performance 52
4.1.2 Descriptive statistics 52
4.1.3 Approach speed 53
4.1.4 Passing distance 53
4.1.5 Bicycle speed 55
4.2 Metrocount results (fixed location motorist speeds) 55
4.3 2-1 treatment – motor vehicle speeds 55

4.4 2-1 implementation site observations 56
4.5 Summary 57
5 Project implementation: cost analysis 58
6 Discussion 59
6.1 Baseline cyclist-motorist interaction data 59
6.1.1 Passing distance 59
6.1.2 Motorist approach speed 59
6.2 Treatment findings 60
6.2.1 Advisory signage 60
6.2.2 Sharrows (shared lane arrows) 60
6.2.3 2-1 treatment in New Zealand 61
6.3 Lessons for 2-1 designs 62
6.3.1 Explicit behaviour-based signage 62
6.3.2 Repeat signage 62
6.3.3 Site selection 62
6.3.4 Edge lines 62
6.4 Lessons around trialling new road environments 63
6.4.1 Community consultation, education and awareness 63
6.4.2 Balancing innovative design with practical implementation 63
6.4.3 Additive versus solitary treatments 64
7 Recommendations 65
8 References 66

Executive summary

Research aim

The NZ Transport Agency has expressed concern about the lack of improvement in fatal and serious cyclist injuries on low-volume rural roads since the *Safer Journeys* strategy was launched. This investigation aimed to determine how to cost-effectively improve the safety of people who cycle on low-volume rural roads in New Zealand. A low-volume rural road was classified here as a non-state highway road in a rural area with a daily traffic volume of 3,000 vehicles/day or less. In the NZ Transport Agency's One Network Road Classification, this definition equates to roads at the 'Primary collector' level or below.

Literature review and crash analysis

A total of 354 cyclist-motorist crashes were recorded on low-volume rural roads in New Zealand between 2004 and 2013, resulting in 18 fatalities, 96 severe injuries and 236 minor injuries. While cycle-only crashes are also important in a rural context, where road maintenance is typically lower, the focus of this study was to examine cyclist-motorist interactions as that is where existing data and literature suggest there is a large social cost. Illustrating this fact, the total social cost of aforementioned crashes was estimated to be over NZ$161million (or $16 million per annum). Overtaking and rear-end crashes (40% combined) were the main crash types associated with these low-volume rural roads crashes.

Internationally, there has been a range of solutions put in place to enhance the safety of cyclists on rural roads. The Dutch 2-1 solution has been argued to be the most successful, which involves centreline removal, 1.5m to 2m wide cycle edge strips on each side of the road, and a speed limit of 60km/h. Threshold treatments include posted speed limits, transverse lines and physical obstacles.

Trial treatments

Following the literature review and crash analysis, two treatments were identified for trial:

- advisory signs on passing distance
- 2-1 layout (adapted to the New Zealand context) + rural sharrows (shared space arrows) on curves + 60km/h speed limit.

Unique baseline data was also collected. The 2-1 component appeared to be intuitive to most drivers and riders, but was discontinued after a 24-hour observation period based on safety reasons and public complaints. The sharrows in this section were left on the ground so that the two treatment conditions became the signage treatment and the sharrows treatment.

Trial measures and instrumented bicycles

The performance of the road treatments was measured in real-world settings to ensure ecological validity. Driver behaviours were observed naturalistically, using the following key performance measures:

- approach speed (of passing vehicle)
- passing distance (distance from cyclist to vehicle)
- bicycle speed.

Metrocounters also measured overall speed data of all motorists at two locations. Cyclist and driver data was obtained using an integrated suite of instrumentation on four bicycles. The instrumentation included:

- an ultrasonic device to capture the separation distance between cyclists and vehicles
- a radar device to capture the speed of approaching vehicles
- a rear-facing camera to capture vehicles as they approached
- a GPS unit to determine cyclist position on the route.

The route for the on-road trial was located in the Waipa District and was selected as it is a relatively low-volume rural road (AADT <1000) that is popular with local cyclists for training and recreational rides. Eleven cycling participants were recruited from cycling clubs and local contacts in the wider area. Drivers included all vehicles that travelled on the route during the trial times.

Results

No significant differences were found between the signage or the sharrow treatments and baseline on any of the three key performance measures taken by the instrumented bicycle: approach speed, passing distance or bicycle speed. The lack of significant differences between baseline and treatments did, however, allow the data to be combined to provide unique baseline data for the three dependent variables for these kinds of roads in New Zealand (see the table below). It also revealed that about four in every five drivers provide cyclists with the recommended (ie 1.5m or greater) passing distance.

The Metrocount data indicated that there was no change in average free-flowing vehicle speed as a result of the sharrows, but there was a 2km/h speed reduction in the signage treatment area. There was also a positive daytime finding for the 2-1 design, where the design was able to reduce average motorist speeds from about 90km/h to about 62km/h. However, night speeds for motorists travelling through the 2-1 design were still higher than desirable.

A summary of key performance measures

Performance measure	Average driver approach speed	Average cyclist speed	Average driver passing distance	Driver compliance with 1.5m recommended distance (%)
Baseline	76.8km/h	23.67km/h.	212cm	82%

Based on the findings of this project, Opus Research recommends that the following be considered:

1. **Further 2-1 trials in the New Zealand context:** Future trials are recommended to further inform the 2-1 design applicability in the New Zealand context. These design trials need to be conducted in conjunction with robust threshold and midblock treatments, including more active speed management measures (particularly at night). Complementary behaviour-based signage must be used to ensure all road users in the treatment location are exposed to explicit information demonstrating correct user behaviour. Similar, low-volume rural road designs with limited space (such as roads with no centre lines) could also be used to draw comparisons with user behaviour on existing New Zealand roads.
2. **Community consultation, communications and engagement strategy:** While the 2-1 design may be intuitive to most motorists and cyclists, any future trials of the 2-1 design (or other new or innovative designs) must be accompanied by a robust communications and engagement strategy, including education about new road layouts use and potential benefits. This communications strategy should be the joint responsibility of the appropriate road controlling authorities and the research and evaluation team, and should obtain a high level of community buy-in before trials proceed to implementation.

3 **Advisory distance signs:** Use advisory distance signage as part of a suite of measures to improve the safety of cyclists on rural roads. These signs have been shown to lead to a significant reduction in vehicle speed (a speed reduction that has the potential to benefit the safety of all road users).

4 **Standardised advisory signs:** The NZ Transport Agency consider the development of a standardised advisory sign to encourage desirable overtaking behaviour when passing cyclists, and guidelines for its use to ensure consistency across the national network. The sign used in this project is similar to that being trialled for high-risk motorcycling routes (so is consistent), and has been shown to lead to speed reductions, so could serve as a starting point for this development.

5 **Baseline cyclist- driver data:** A robust baseline of how drivers and riders interact in different settings and road hierarchies would better inform and monitor safety intervention outcomes.

Abstract

This study aimed to determine how to cost-effectively improve safety for people who cycle on low-volume rural roads in New Zealand. Following a literature review and Crash Analysis System consultation, two treatments were identified for on-road trial: 1) Advisory signs on passing distance and 2) A 2-1 layout (adapted to the New Zealand context). The latter became a shared space arrow treatment after the 2-1 component was discontinued for safety reasons. The key performance measures of vehicle approach speed, vehicle passing distance, and bicycle speed were measured using an integrated suite of instrumentation on four bicycles. No significant differences were found between either of the treatments and baseline on any of these measures; however, Metrocount data indicated that there was a significant 2km/h speed reduction in the signage treatment area. The instrumentation data provided baseline measures of approach speed (76.8km/h), passing distance (2.12m) and bicycle speed (23.67km/h). Recommendations for future work on cyclist safety on low-volume rural roads include the development of standardised share the road signage, the further adaptation of the 2-1 design to the New Zealand context, the implementation of a robust communication and engagement strategy for innovative research, and baseline data collection to better inform countermeasures.

1 Introduction

The NZ Transport Agency (hereafter referred to as the Transport Agency) has expressed concern about the lack of improvement in fatal and serious cyclist injuries on low-volume rural roads since the *Safer Journeys* strategy was launched in 2010. It appears that a significant proportion of these injuries result from drivers not allowing cyclists sufficient space while overtaking. This investigation examines how to cost-effectively improve safety for people who cycle on low-volume rural roads in New Zealand. A low-volume rural road is classified here as a non-state highway road in a rural area with a daily traffic volume of 3,000 vehicles/day or less. In the Transport Agency's One Network Road Classification, this definition equates to roads at the 'Primary collector' level or below.

1.1 Key research questions/project objectives

The Transport Agency required an evaluation of the safety benefits and cost-effectiveness of different road layouts on low-volume rural roads in order to determine the most cost-effective way to improve safety for cyclists using these roads in New Zealand. The key objectives of this research were therefore to:

1 Review and evaluate New Zealand and international literature examining the effectiveness of different road layouts, focusing specifically on research around alternative road layout options, measures of the effectiveness of such options, and how alternative road layouts (new types and combinations) can be used to optimise value.

2 Determine the most cost-effective way to improve safety for people who cycle on low-volume rural roads and investigate the relative risk of cycling on New Zealand's current range of road layouts.

3 Provide a full technical report detailing the project methodology and findings to the Transport Agency.

4 Provide a comprehensive implementation plan which outlines the steps required to execute any changes to road treatment based on the research findings, and identify relevant Transport Agency documents and guidelines that may require adjustment in light of the research findings.

1.2 Key project stages

The project consisted of six main stages aimed to address the key research objectives identified above.

Stage 1 – Review of literature and international practice

The literature review stage critically reviewed and evaluated New Zealand and international studies as well as meta-analyses that have examined the effectiveness of different road layouts. It focused specifically on alternative road layout options, measures of effectiveness of these options, and how alternative road layouts (new types and combinations) could be used to identify the most cost-effective safety solutions for cyclists on low-volume rural roads in New Zealand. The purpose of the literature review was threefold:

1 To identify the best road treatments available by trialling their efficacy for optimising cyclist safety

2 To identify measures of effectiveness of different road treatments

3 To limit the road treatment options being examined to the best options available based on relative efficacy in order to inform the subsequent experimental stage of the research.

Stage 2 – Crash data analysis and method development

The purpose of this stage was to identify the locations of recorded fatal and serious injury crashes involving cyclists on low-volume rural roads using the Transport Agency's Crash Analysis System (CAS). Additionally, the CAS dataset provided information on fatal and serious injury incident causes which detected additional factors that may have contributed to cyclist crashes low-volume rural roads.

Stage 3 – Treatment selection, equipment development and testing

The crash analysis, alongside the findings from the literature review, informed the selection of the most appropriate treatments and best locations for the experimental road trial (see Stage 4). The selection process involved an expert Steering Group and Traffic Control Devices (TCD) Committee. Technical piloting was also conducted during this stage to ensure that all necessary measures could be obtained from the proposed equipment and technical set-up.

Stage 4 – Experimental study

The agreed treatments were tested in this stage. The performance of road treatments was measured in real-world settings to ensure ecological validity. Driver behaviour in response to cyclists was observed naturalistically, using key performance measures. The specific objective measures of effectiveness were informed by the literature review and depended on the treatments selected for trial.

The quantitative data from the experimental study and survey were analysed using the statistical analysis program 'R' which allows for easy manipulation and recoding of data, as well as detailed data checking and quality assurance processes.

Stage 5 – Cost-effectiveness analysis

A cost-effectiveness analysis of the various road treatments was trialled in this stage. Factors considered in this analysis were:

- implementation costs
- operational and maintenance costs
- the likely user
- forecast of benefits
- crash or injury severity reduction along with new user.

Stage 6 – Final reporting

The final report combines the findings from the literature review, CAS analysis, experimental trials, and cost-effectiveness analysis, as well as set of recommendations for the Transport Agency drawn from such findings.

2 Review of literature and practice

2.1 Introduction

The Transport Agency has expressed concern about the lack of improvement in fatal and serious cycle injuries on low-volume rural roads since the *Safer Journeys* strategy was launched. *Safer Journeys* is the Ministry of Transport's road safety strategy for 2010–2020, which aims to create a safer transport system that is increasingly free of death and serious injury (NZ Transport Agency 2014a). Although fatal and serious injury incidents involving cyclists occur most frequently on New Zealand's urban roads (92%), over half of cyclist deaths occur on the open road (Ministry of Transport 2013). This research focuses on low-volume rural roads which have been defined as rural roads with a primary collector function or lower as per the One Network Road Classification (NZ Transport Agency 2014b). These roads have an average typical daily traffic volume of up to 3,000 vehicles, and with current speed limits between 70km/h and 100km/h.

It is highly likely that the popularity of cycling on rural roads will increase over coming years given the Government's $50 million investment, and community co-funding investment of $30 million, in Nga Haerenga: The New Zealand Cycle Trail. This trail is a partnership project that seeks to:

> *build a network of cycle trails that would not only provide a healthy and enjoyable way for Kiwis and international visitors to see the country, but would also generate economic, social and environmental benefits for our communities.* (Nga Haerenga: The New Zealand Cycle Trail 2014)

Currently, it involves mostly off-road trials but on-road routes are increasingly being added, with the eventual aim of 'enabling locals and international visitors to explore all of New Zealand by bike' (Nga Haerenga: The New Zealand Cycle Trail 2014). Given that more New Zealanders and international visitors may be cycling on New Zealand's rural roads as part of the New Zealand Cycle Trail in coming years, it is imperative to proactively mitigate potential risk to these road users.

2.2 Context

An initial Crash Analysis System (CAS) review revealed that a high proportion of rural road fatal and serious injury crashes involving cyclists in New Zealand result from drivers not giving cyclists sufficient space while overtaking.

Recent research shows that people in the Waikato region predominantly cycle on rural roads for recreational purposes, rather than for transport purposes (Waikato Regional Council 2014). This study found that 'rural cyclists' prefer to cycle on lower-volume rural roads because they feel they are safer than higher-volume rural roads, despite low-volume roads usually being narrower and less likely to have marked shoulders.

Crash data analysis from North Carolina, USA, found that, while urban crashes involving a cyclist and a motorist were more likely to occur at intersections, rural crashes involving a cyclist and a motorist were more likely to occur midblock. The most common rural motorist–cyclist crash was either a cyclist entering the path of the motorist, or when motorists performed a passing manoeuvre. Two-lane rural roads also had the highest frequency of crashes across all road types (Carter and Council 2007).

2.3 CAS analysis

2.3.1 Methodology

Cycle crash data for crashes occurring on low-volume rural roads in New Zealand was sourced from the Transport Agency's Crash Analysis System (CAS) for the 10-year period 2004–2013. This dataset provides information on the vehicles, causes and movements of all reported crashes, as well as the number of fatalities, serious and minor injuries that occurred (NZ Transport Agency 2012). In the CAS approach, the following definitions are used for each injury outcome:

- Fatalities: a death occurring as the result of injuries sustained in a road crash within 30 days of the crash.
- Severe injuries: fracture, concussion, severe cuts or other injury requiring medical treatment or removal to and treatment in hospital.
- Minor injuries: injury which is not 'serious' but requires first aid, or which causes discomfort or pain to the person injured.

The CAS procedure began with a database query that selected crashes involving at least one cyclist in an open road setting. To restrict the dataset to those that took place only on the road types of interest, each crash was geocoded to a point location in a GIS system. Each crash was then spatially referenced against a national road network dataset, and crashes that did not occur on low-volume rural roads were subsequently removed. State highways and cyclist only crashes were excluded from this dataset (cyclist only crashes have only been recorded in CAS since 2013).

To identify geographic crash 'hot-spots' at a national level, the point location of each crash was mapped and a 5km buffer applied. This buffer was used to count the number of crashes that have occurred within 5km of each location across the study period.

2.3.2 Crash statistics

2.3.2.1 Temporal trends

There were 258 road crashes involving all road users on New Zealand roads in 2013, a reduction of 183 (41%) over the 10-year period starting 2004. Furthermore, evidence reveals variation in the rate of decline of crashes by travel modes during this time period (figure 2.1). Fatalities among drivers and passengers of vehicles have decreased by 51% since 2004. The relatively low number of motorcyclist, cyclist and pedestrian fatalities makes it difficult to determine an upward or downward trend, however, figure 2.1 suggests that vehicle fatalities have decreased at a much faster rate compared with all other modes. An average of 42 motorcyclists, 9 cyclists and 35 pedestrians died on New Zealand roads each year from 2004 to 2013.

Overall, cyclist fatality crashes on all New Zealand roads decreased between 2004 and 2013 by approximately 16% per year (figure 2.2). Given the small number of annual cyclist fatalities, these figures need to be interpreted with caution as a change in count of one death has a large impact on annual trends. The important point is the increase of cyclist fatalities as a percentage of total road deaths between 2004 and 2013. At the beginning of the period, cyclists accounted for 1.6% of the national road toll compared with 3.1% in 2013. These statistics do not take into account any changes in cyclist trips made during this period.

Figure 2.1 Road crash fatalities by road user type on all roads 2004–2013

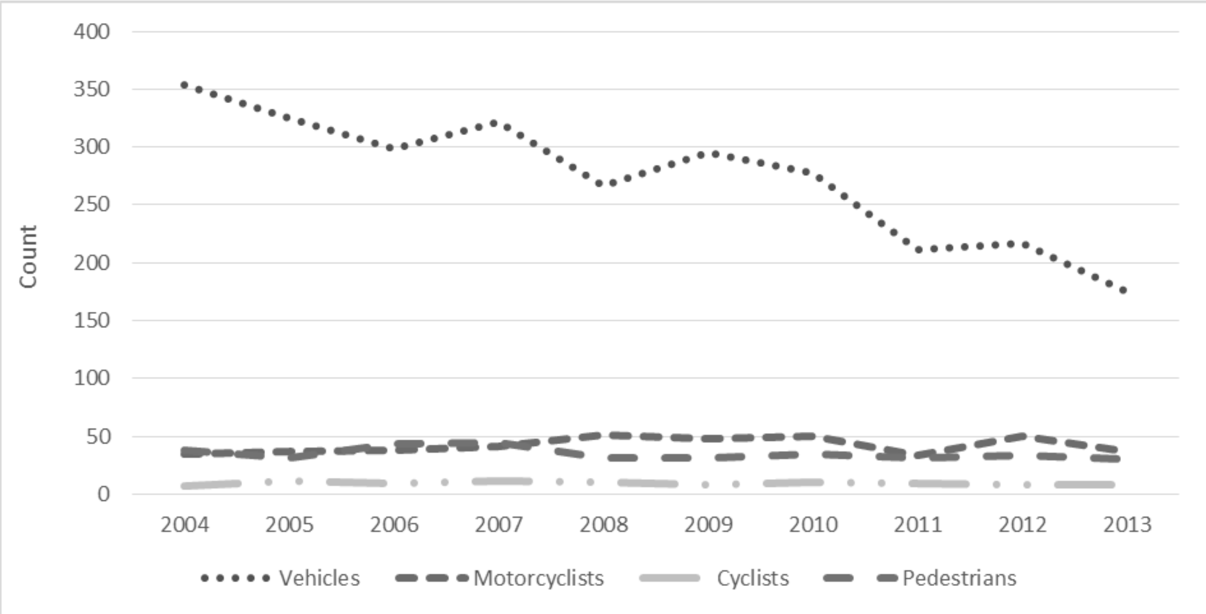
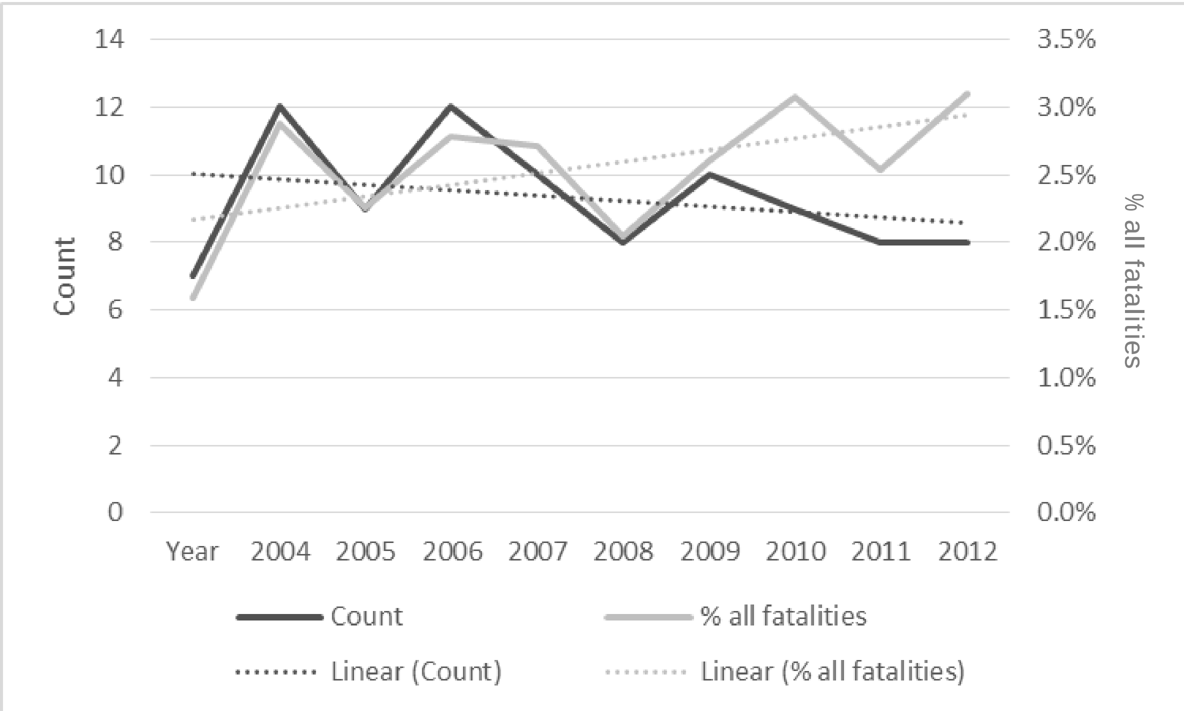
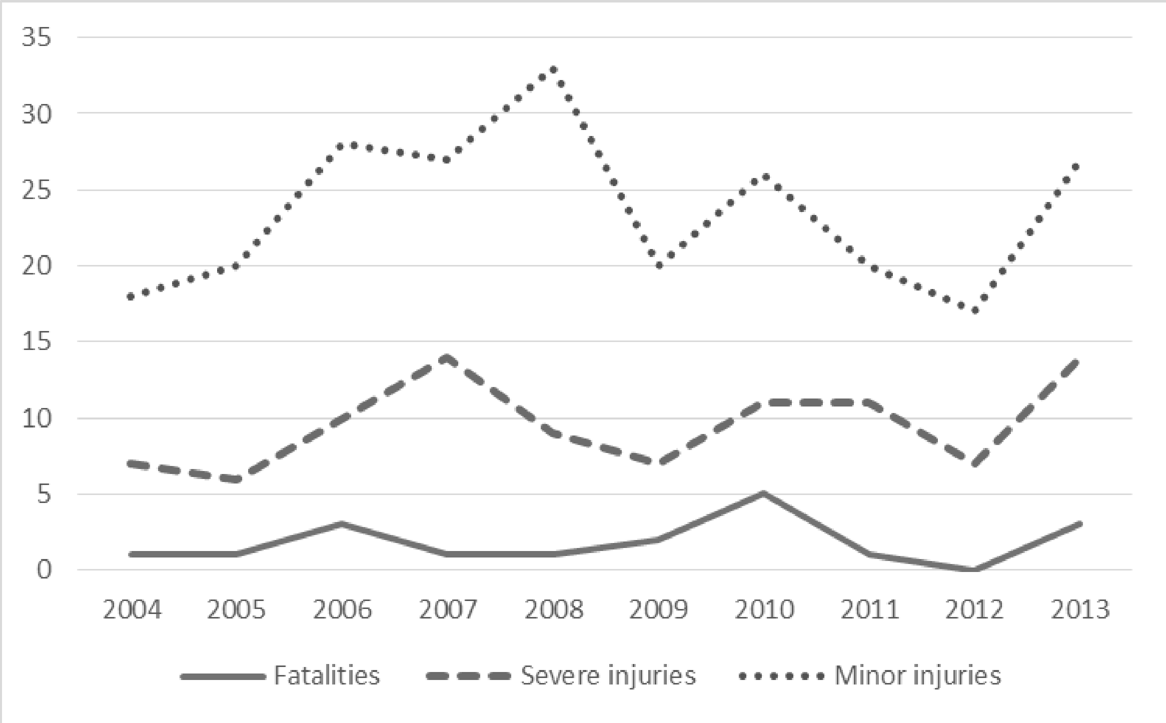


Figure 2.2 Cyclist fatalities on all roads 2004–2013



On low-volume New Zealand rural roads (non-state highways) from 2004 to 2013, there was a total of 354 crashes involving all road users. The outcome from these crashes was 18 fatalities (from 16 crashes), with a further 96 severe injuries and 236 minor injuries. There was some fluctuation in the number of fatalities and severe injuries from crashes involving cyclists during the same period (figure 2.3). There was little variation in the number of fatalities and minor injuries to cyclists during this period while reported severe injuries rose slightly.

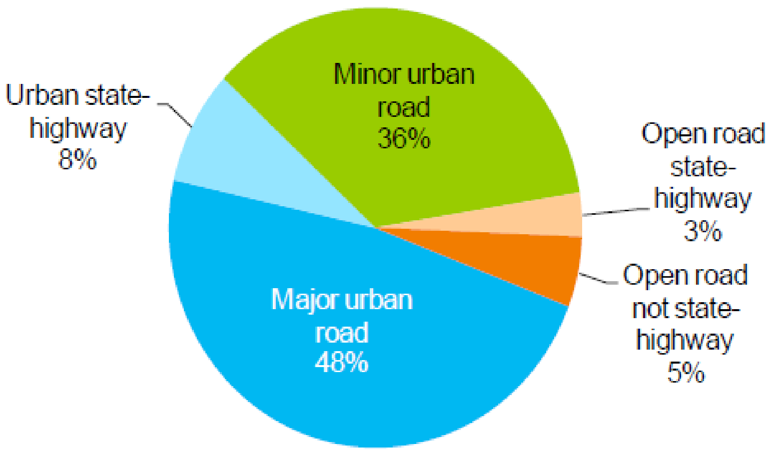
Figure 2.3 Cyclist fatalities and injuries on low- volume rural roads 2004–2013



2.3.2.2 Crashes by road type

Approximately 5% of all cyclist fatality and injury crashes occur on open-road non-state highway settings, most of which are low-volume rural roads (figure 2.4). A consequence of this low proportion is that few resources are invested to improve cycling safety on rural roads. Instead the focus is predominantly placed on urban areas. Yet the social cost of rural cyclist crashes to New Zealand is high.

Figure 2.4 Cyclist deaths and injuries in motor vehicle crashes by road type 2008–2012



(Source: NZ Transport Agency Cycle Forum background paper)

2.3.2.3 Social cost of crashes

The *Economic evaluation manual* (EEM) provides standardised social costs for crashes occurring on rural roads by travel mode (NZ Transport Agency 2013a). The EEM's estimated social cost of cyclist crashes as of July 2006 is outlined in $NZ as follows:

- fatality in a 100km/h speed limit zone $3.1million
- serious injury crash $325,000
- minor injury crash $19,000.

The EEM recommends a factor of 2.3 and 7.5 be applied to serious and minor injury crashes occurring on 100km/h remote rural roads to account for under-reporting of non-fatal cyclist crashes. Based on the crash statistics presented here, the estimated social cost of cyclist–motorist crashes on low-volume rural roads in New Zealand was over $90million ($NZ July 2006) between 2004 and 2013. After adjustment for under-reporting factors, the estimated cost of these crashes is over $160 million ($NZ July 2006). See table 2.1.

Table 2.1 Social cost of cyclist- motorist crashes on low- volume rural roads 2004–2013 ($NZ July 2006)

Injury outcome	Number of people	Social cost	Adjusted	Social cost
Fatal	18	$55,800,000	18	$55,800,000
Severe	96	$31,200,000	221	$71,825,000
Minor	236	$4,484,000	1,770	$33,630,000
Total	354	$91,484,000	2,009	$161,255,000

2.3.3 Vehicle movements

Crash reports record the principal movements of vehicles involved in a crash. By examining such movements, it is possible to determine what high-risk interactions most commonly relate to crashes on low-volume rural roads. Table 2.2 outlines the most common movement codes attributed to the key vehicle involved in crashes on low-volume rural roads from 2004 to 2013. The key vehicle is not an indication of fault but the role played in the crash event.

The most common open-road vehicle movements leading to crashes in this period were during overtaking and lane changes (21.9%). Stratified by the key vehicle, there is a roughly even split between cyclists and motorists in control of the vehicle performing the overtaking or lane change manoeuvre during the crash (22.5% and 21.5% respectively). The second most commonly recorded movement was rear-end crashes (18.0%). For these crashes, it was more common for a motorist to be approaching a cyclist from the rear (24.4%) than the opposite scenario (4.9%).

Table 2.2 Recorded movement of primary vehicle in cyclist versus motor vehicle crashes

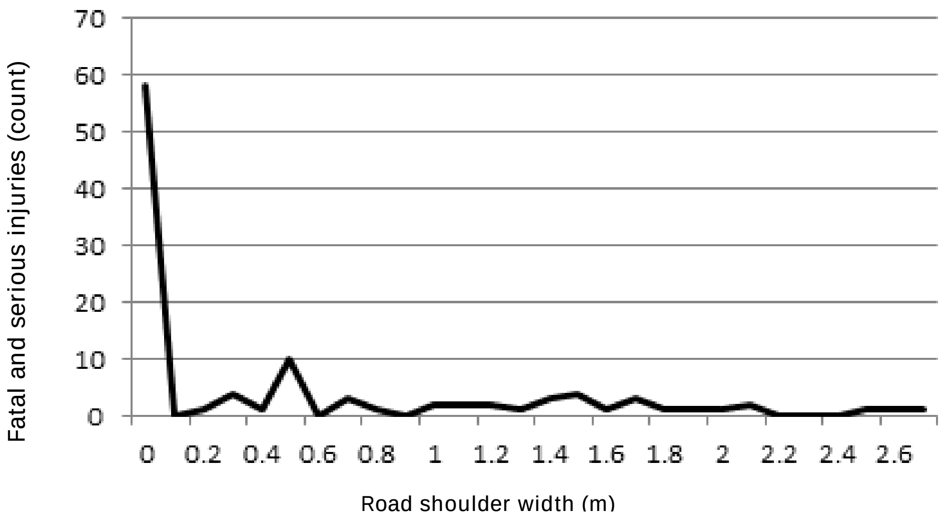
Vehicle movement	Key vehicle		
	Bicycle	Motor vehicle	All vehicles
Overtaking and lane change	**22.5%**	**21.5%**	**21.9%**
Rear end	4.9%	**24.4%**	**18.0%**
Crossing (vehicle turning)	**16.7%**	9.1%	11.6%
Head on	**15.7%**	6.7%	9.6%
Crossing (no turns)	3.9%	11.5%	9.0%

Vehicle movement	Key vehicle		
	Bicycle	Motor vehicle	All vehicles
Turning versus same direction	5.9%	10.0%	8.7%
Right turn against	7.8%	3.8%	5.1%
Merging	5.9%	4.3%	4.8%
Manoeuvring	4.9%	3.8%	4.2%
Collision with obstruction	8.8%	0.5%	3.2%
Lost control or off road (straight roads)	2.9%	1.0%	1.6%
Cornering	0.0%	2.4%	1.6%

Note: Sample size of 16 fatal, 91 serious injury, and 204 minor injury causing crashes.

Examined another way, the combination of overtaking and lane changing with rear-end crashes accounts for 40% of all crashes on low-volume rural roads. These crash types are typical of narrow road situations. Head-on crashes, which occur at a higher ratio for cyclist–motorist crashes than for motorist–motorist crashes, are generally connected to high speed. In the police crash reports it is posited that for cyclists this is related to high speed, most likely where the cyclist is riding downhill and cutting corners on curves. This would indicate speed as a factor for both cyclists and motorists. Previous analysis of shoulder width versus percentage of fatal and serious crashes on low-volume rural roads shows the negative relationship between crashes and shoulder width (figure 2.5). This highlights shoulder width as a key factor in low-volume rural crashes.

Figure 2.5 Fatal and serious injury cyclist crashes by road shoulder width



Source: Tim Hughes, NZ Transport Agency

Slightly more than half (51%) of all cyclist–motorist crashes on low-volume rural roads occurred on mid-block sections of the roadway. Crashes recorded at junctions are split between intersections (38%) and driveways (11%). Cyclists or motorists failing to give way was a common cause of crashes at intersections while inattention and failing to look before merging into traffic were often cited in driveway crashes for both cyclists and motorists pulling out into the traffic lane.

2.3.4 Contributing factors

A range of factors that ‘probably contributed to crashes’ are also recorded on police crash summary reports and are subsequently coded into the CAS dataset. For crashes on low-volume rural roads between 2004 and 2013, three behaviours contributed to over half (54.8%) of the cyclist crashes on low-volume rural roads, as displayed in table 2.3 below. Table 2.3 also shows the crashes split by the attributed vehicle (where either a rider or motorist’s behaviour was attributed as being the primary cause of the crash).

Among crashes where failing to give way was a potential contributing factor, failing to give way at a give-way sign was the most frequently reported behaviour for both motorists (57.1%) and cyclists (40.5%). When failing to keep left, 69.6% of motorists and 30.4% of cyclists were considered to have strayed too far left or right from their path. Finally, for crashes caused by parties who did not look or see another party in time, failing to look behind when changing lane position or direction was reported for both cyclists (78.6%) and motorists (54.5%).

Table 2.3 Potential contributing factors by road user type attributed as the primary cause of crash

Behavioural factor	Attributed road user		
	Cyclist	Motorist	Total
Failed to give way	31.9%	21.0%	24.7%
Failed to keep left	19.8%	19.7%	19.8%
Did not look or see another party in time	12.1%	9.4%	10.3%

2.3.5 Geographic locations

It is important to understand how rural cycle crashes are spread across the New Zealand transport network to inform a targeted approach to reducing risk in a safe system. Figures 2.6 and 2.7 present the geographic locations of cyclist–vehicle crashes on low-volume rural roads based on the number of crashes that occurred within a 5km radius between 2004 and 2013. There were a higher number of crashes in the North Island during this period, with the majority occurring on urban fringes. Crash ‘hot spots,’ where a number of crashes were recorded within a 5km radius, were most common to the north and south of Auckland, and around Hamilton, Hastings and Christchurch. These crash locations were used to help inform the site selection process for the trial (see section 2.5.4). The crash locations are likely to relate to common riding routes and exposure effects, for example, many are located nearby urban centres. However, a lack of robust cycle count data means this cannot be confirmed.

Figure 2.6 North Island cyclist-vehicle crash locations 2004–2013

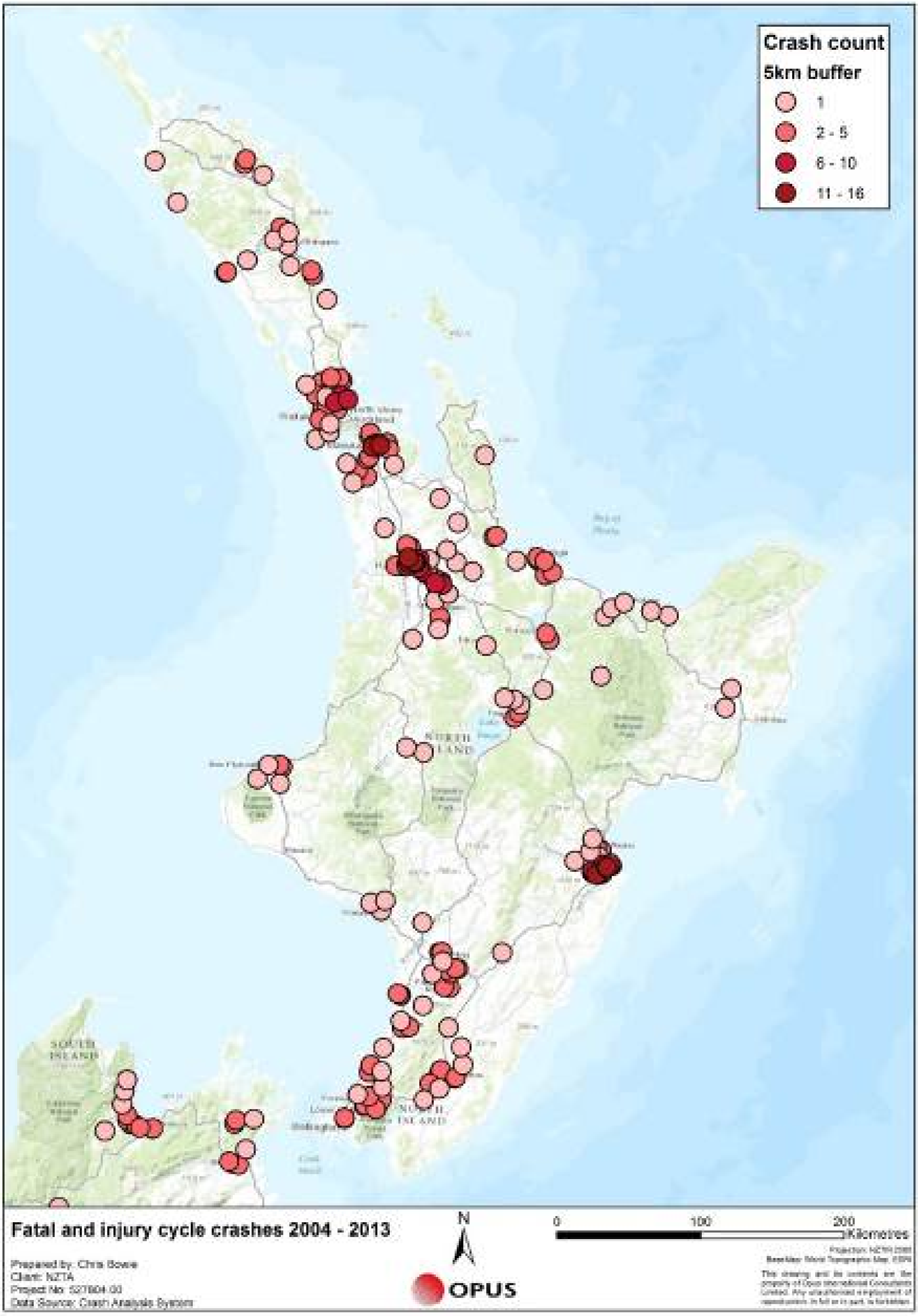
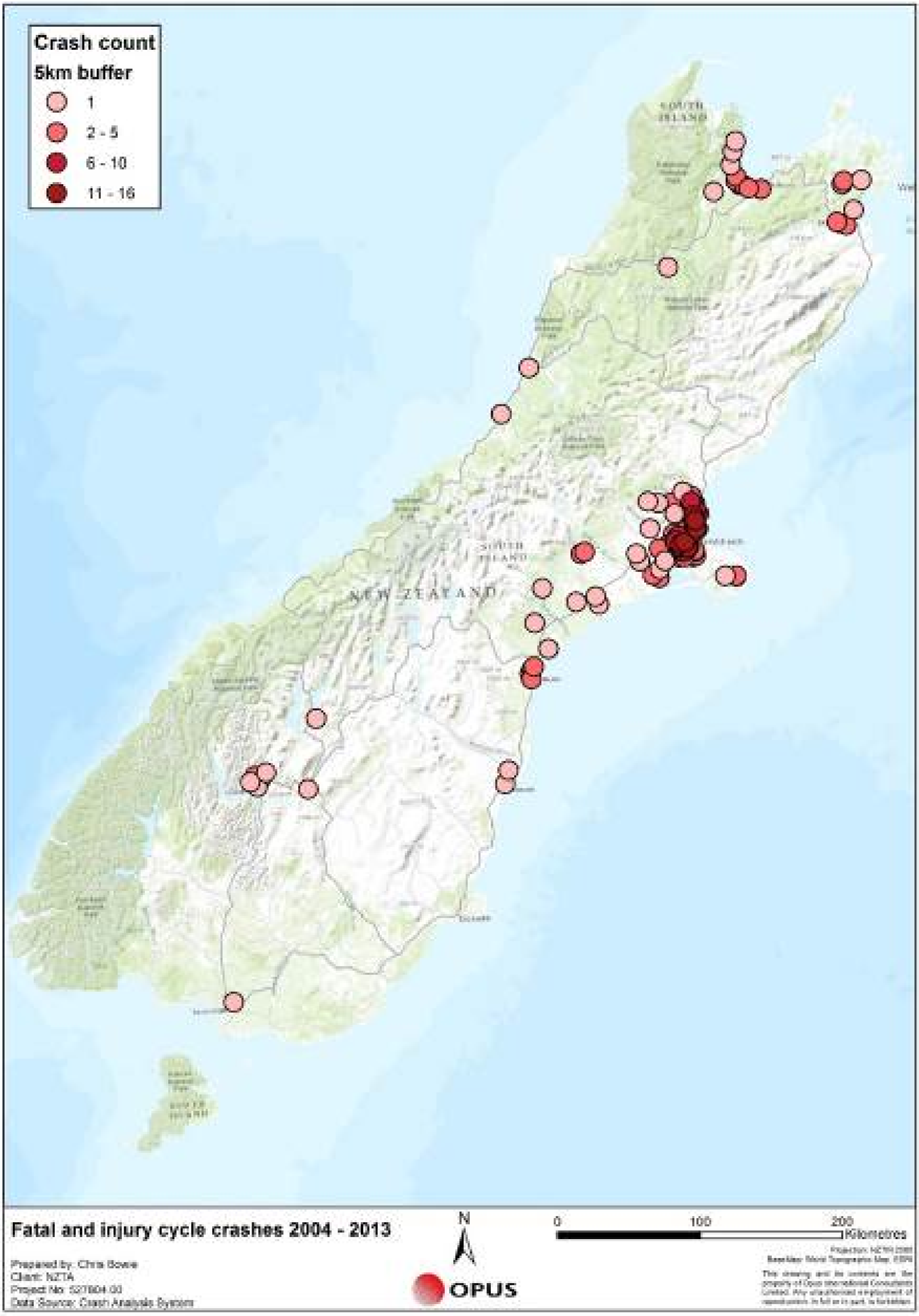


Figure 2.7 South Island cyclist-vehicle crash locations 2004–2013



2.3.6 Key findings drawn from CAS analysis

- A total of 354 cyclist–motorist crashes were recorded on low-volume rural roads in New Zealand between 2004 and 2013.
- These crashes caused the following outcomes to the cyclists involved: 18 fatalities, 96 severe injuries and 236 minor injuries.
- The estimated social cost of fatal and injury causing crashes involving cyclists during the period was over NZ$161million (June 2006) after adjusting for under-reporting of severe and minor injuries.
- Overtaking, lane changing and rear-end crashes together make up 40% of all crashes on low-volume rural roads.
- In head-on crashes cyclists were more likely to cross into the path of motorists than the other way around. Cyclist speed on corners while riding downhill may be a factor in these crashes.
- Specific movements most common to cyclists who are involved in such crashes are: a) travelling straight into the path of a motorist turning across from the left while pulling out, and b) changing lanes to the right.
- Motorists are most likely to rear end a cyclist travelling at a slower relative speed and to travel straight into the path of a cyclist crossing them from a right angle (eg side road).
- Common behavioural faults of cyclists and motorists include failing to give way, failure to keep left, and poor observation of other road users.
- Crashes are often located close to urban centres. This is expected given the likelihood of a higher incidence of cyclists in these areas.

2.4 Road treatments and measures

There is a range of possible treatments available for improving cycle safety on New Zealand's low-volume rural roads. Many recommended treatments to improve cycle safety, particularly on higher-speed and/or higher-volume roads, focus on the creation of physically separated cycle tracks or the use of sufficiently wide and well delineated hard shoulders. However, these treatments can be expensive to implement and may not be the most cost-effective approach to improving cyclists' safety on New Zealand's narrow, low-volume rural roads. As such, this review considers alternative, more cost-effective solutions. The purpose of the literature review is threefold:

1 To identify the best road treatments available to trial their effectiveness in a New Zealand context

2 To identify measures of effectiveness to determine the efficacy of different road treatments

3 To inform the experimental phase of this research, especially by limiting the road treatment options being examined to the best options available based on relative effectiveness.

In particular, this review focuses on changes that could be made to the road layout along with other cost-effective and complementary measures, such as signage. First, independent measures which may reduce motorists' speed, and thus improve cycle safety, are discussed, and second, international best practice approaches to improve cycle safety on low-volume rural roads are identified and discussed, including studies which measure the effectiveness of these approaches.

Only publications available in the English language were included in this review. It is important to note that most low-volume rural road cycle safety best practice comes from the Netherlands and Denmark.

Fortunately, the Dutch in particular produce many studies, reviews and policies in English so they were able to be included. Overall, there is little evidence that countries such as New Zealand, Australia, the UK and the US have addressed cycle safety on low-volume rural roads.

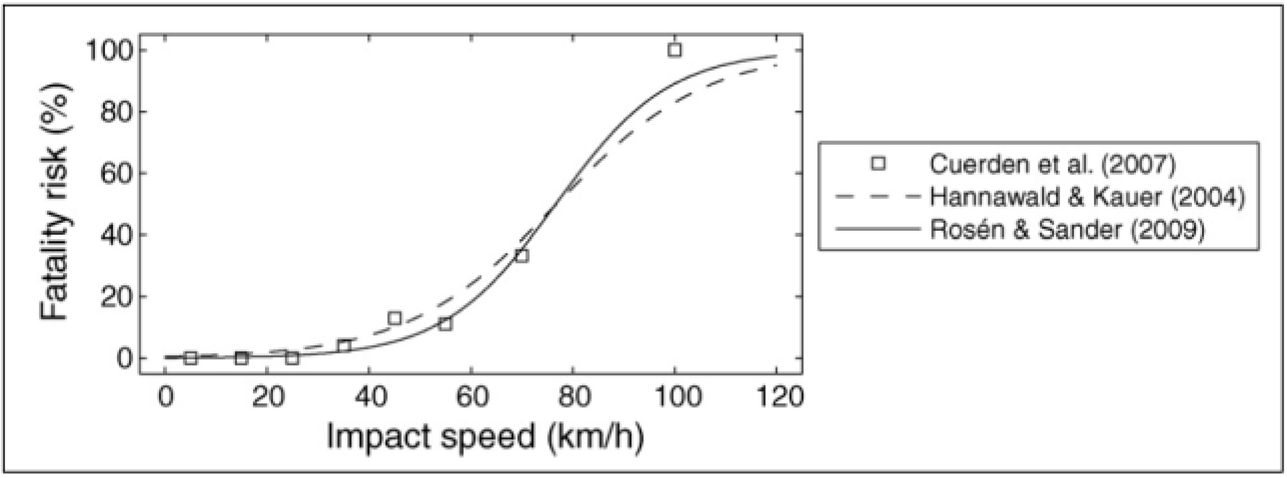
2.4.1 Safer speeds for shared rural road space

Alternate layouts may be a suitable treatment for New Zealand's low-volume rural roads under the One Network Road Classification, where such roads should have a 'strong shared philosophy between active road users (if present) and vehicular traffic', and that 'active road users [can] expect [an] environment appropriate to their needs' (NZ Transport Agency 2013b). If cyclists are sharing narrow rural roads with motorists, then measures which effectively reduce motorist speed are likely to be the most important way to improve cycle safety, by reducing both the likelihood and severity of a crash.

In general, as speed increases so do crash rates and severity (Aarts and van Schagen 2006; SWOV 2012a). Elvik (2009) found that crash risk and severity tend to increase more rapidly with rising speeds on rural roads than on urban roads, and studies have found that roads with larger speed variances are less safe (they have a higher crash risk) than those with smaller speed variances (Aarts and van Schagen 2006). Additionally, higher speeds decrease the scope of drivers' peripheral vision, reducing their ability to notice hazards on the road side, such as people walking or cycling (OECD/ECMT 2006).

The difference in mass between cyclists and motorists makes cyclists particularly vulnerable in a high-speed crash. Illustrating this point, figure 2.8 from Rosen et al's (2011) study shows that the fatality risk of a person being hit by a car increases rapidly when vehicle speeds rise above 30–40km/h, and a 70km/h impact speed has about double the fatality risk of a 60km/h impact. Earlier studies predicted the fatality risk for pedestrians with an even steeper gradient (eg Anderson et al 1997); however, the more recent predictions may relate to improved vehicle technology in the modern vehicle fleet in relation to vulnerable users (eg Keall et al 2014), advances in medicine, and more robust data (eg see Rosen et al 2011 for a review of data limitations).

Figure 2.8 Pedestrian fatality risk versus motor vehicle impact speed during a collision with a passenger car



Source: Rosen et al (2011)

All of these factors (ie high speed, speed variance, limited peripheral view and difference in mass) mean that cyclists are particularly vulnerable if sharing space with motorists on low-volume rural roads. The OECD recommends that safe speeds for minor rural roads, with a local traffic function and the presence of vulnerable road users, are between 40 and 60km/h (OECD/ECMT 2006). In short, a higher-speed road environment can be described as 'unsafe for shared use'.

2.4.2 Speed reducing measures

Motorist speed is influenced by a wide range of factors, including driver preferences, characteristics and behaviours, the influence of passengers and other road users, vehicle features and the features of the road environment (SWOV 2012b). The measures focused on for this review are those related to the road environment.

2.4.2.1 Speed limits

Motorists are influenced to varying degrees by speed limits, but speed limits are often ineffective if implemented in isolation. In a review by the OECD/ECMT, the authors reported that speed limits alone, on average, reduce speeds by about 25% toward the new limit (OECD/ECMT 2006). For this reason, speed limits should be implemented along with enforcement and education, as well as physical changes to the road environment.

One important way to provide information to road users is through signage. Signage can be used to inform road users of restrictions such as speed limits, and it can also be advisory to inform road users of upcoming or potential hazards. Signage can be fixed, or it can be responsive and dynamic to conditions, such as variable message signs (OECD/ECMT 2006).

Physical changes, or changes to the appearance of the road, can effectively reduce speeds with long-term effect (OECD/ECMT 2006). The Dutch Institute for Road Safety Research (SWOV) suggests that the road environment and posted speed limit should intuitively match in order for the speed limit to be credible. They argue that when speed limits and the road environment do not match, the credibility of the speed limit is eroded and drivers will ‘be more inclined to choose their own speed’, which may be too high or too low (SWOV 2012c; p1). If speed limits are reduced on New Zealand’s low-volume rural roads in order to promote cycle safety without the use of both enforcement and the simultaneous introduction of physical changes to the road environment, it is possible that the reduced limits may not be seen as credible, and thus drivers may continue to drive nearer to the original speed of the road.

The next section describes physical measures which may be implemented, alongside speed limit reductions, to reduce actual speeds on low-volume rural roads. Although these measures have been shown to reduce speed in varying ways, no literature was found regarding their specific effect on cycle safety. However, measures which reduce speed are likely to increase cycle safety by reducing both the likelihood and severity of a crash.

2.4.2.2 Road type and surroundings

In general, motorist travel speeds tend to be lower on roads that are narrow and winding than on roads that are wide and straight. Bends in roads reduce forward visibility and therefore can reduce speed (SWOV 2012b). While reduced speeds are desirable, reduced forward visibility may not be, unless measures are taken to ensure it does not reduce cycle safety. Speeds have also been shown to be lower when the road surface is rough or in relatively poor condition (SWOV 2012b). Again, this may be an undesirable outcome, as road surfaces of variable or poor quality can pose a hazard to cyclists and can cause them to shift laterally and unpredictably from a motorist’s perspective further into the vehicle lane (Walton et al 2005). The roadside quality can consequently become an issue for all road users, including motorists. This aligns with some of the key concerns raised around rural cycling in Australia which included poor road conditions, narrow roads, motorist speed and unpredictable cyclist behaviour (Johnson and Le 2012).

2.4.2.3 Obstacles

Physical obstacles can also be implemented to reduce traffic speeds; however, care must be taken to ensure they do not create conflict between transport modes, such as between people driving and people cycling. Traditionally these measures are used in New Zealand in lower-speed urban locations, so it is important to note their use overseas in rural environments. Roadside gateways can visually narrow the road and can be used to demarcate a transition area. To effectively reduce speed, the road design should also change once the road user is through the gateway.

Among the variety of obstacles used, speed bumps or cushions, and bollards are physical obstacles that have been shown to be particularly effective for reducing motorist speed on rural roads (OECD/ECMT 2006). Figure 2.9 shows the simultaneous use of a traffic island, bollards and a speed cushion to reduce motor vehicle speeds (while allowing cyclists clear passage) on a Dutch low-volume rural road.

Figure 2.9 A traffic island, bollards and a speed cushion on a low- volume, 60km/h Dutch rural road

Source: Schermers and van Vliet (2001)

2.4.2.4 Road markings

Road markings can be used to increase a driver's perception of speed, thus encouraging them to slow down. Such road markings can be longitudinal, running along the carriageway, or transverse, running across the carriageway (Rothenberg et al 2004).

Longitudinal

A review of passive speed control devices by Rothenberg et al (2004) found that there was inconclusive evidence regarding the effect of longitudinal markings on speed. Where such markings visually narrow the roadway they can result in speed reductions; however, they can also offer visual guidance to the motorist which may then encourage higher speeds.

A meta-analysis by Davidse et al (2004) found that the addition of edge line and centre line road markings to previously unmarked roads generally resulted in increased speed and a shift in lateral position towards the edge of the road, both outcomes which may negatively affect cycle safety. This meta-analysis also found that broken lines give less visual guidance and a better reflection of speed than solid lines (Davidse et al 2004). As such, the Dutch road safety guidelines recommend the use of broken edge lines in areas where speed reduction is desired (SWOV 2013). In line with the Dutch meta-analysis, a British study in Wiltshire found that centreline removal on 50km/h roads reduced injury causing crashes and resulted in an average speed reduction of 5km/h (Wiltshire County Council 2004).

Transverse

Transverse markings across a road way include bars (full, partial, or angled) and chevrons. Transverse markings can be placed at a gradually reducing distance to create the illusion of acceleration and cause the driver to reduce speed (Rothenberg et al 2004). A review of studies found that transverse markings could significantly reduce both speed and incident rates, and were particularly useful for lowering speeds when approaching intersections and curves (Rothenberg et al 2004; SWOV 2012b; OECD/ECMT 2006). However, some studies have found that speed-reducing effect of transverse markings could lessen over time (SWOV 2012b; OECD/ECMT 2006).

One style of transverse marking has recently been trialled in New Zealand and resulted in significant long-term reductions in both marginal mean speed as well as 85th percentile speed. This study was part of *NZ Transport Agency research report 423* (Martindale and Urlich 2010) and includes a comprehensive literature review of transverse marking types and studies. Given the effectiveness of transverse markings on vehicle speed, these may be a suitable treatment to trial on New Zealand's low-volume rural roads, particularly in places where reduced speeds are imperative. Consideration should be taken to ensure any markings are designed to ensure they do not pose a stability hazard to cyclists (see Walton et al 2005 for a discussion regarding road marking stability hazard for cyclists).

Figure 2.10 shows the use of broken longitudinal road markings and transverse lines, coupled with bollards and signage, to slow traffic on a Dutch low-volume rural road. Also note that these measures allow for the uninhibited passing of cycle traffic on each side of the road.

Figure 2.10 Broken longitudinal road markings and transverse lines, coupled with bollards and signage, to slow traffic on a Dutch low- volume, 60km/h rural road

Source: Schermers and van Vliet (2001)

The next section discusses international best practice approaches to improve cycle safety on low-volume rural roads, including studies which measure the effectiveness of these approaches.

2.4.3 Case studies

2.4.3.1 The Dutch approach: Edge strips on rural access roads (including the 2- 1 design)

Context

The Dutch 'Sustainably Safe' approach involves categorising roads based on their function, and using standardised and consistent road markings so that people can instantly recognise the type of road they are using and adapt their behaviour accordingly (Davidse et al 2004). Following this approach, the Dutch Sustainable Safety guidelines recommend that low-volume rural roads in the Netherlands (those that provide a minor traffic function) are converted into rural access roads. As of 2008, 63% of Dutch low-volume rural roads have been converted to rural access roads (Weijermars and Van Schagen 2009 in SWOV 2013).

Midblock treatments for rural access roads

In the Dutch approach, rural access roads are designated for use by all transport modes and have a speed limit of 60km/h. Dutch rural access roads have no directional separation or centreline, no travel lanes and intersections are not grade separated (Schermers and van Vliet 2001). Rural access roads which are very narrow are not intended for cyclists, and have either no road markings (those <4.5m wide) or broken edge markings on the each side of the road (carriageway between 4.5–5.5m) (Schermers and van Vliet 2001; SWOV 2013).

Dutch guidelines for edge strips suitable for cyclist use on rural access roads stipulate that the carriageway must be at least 5.5m wide (SWOV 2013; Schermers and van Vliet 2001). A single travel lane is available for motor traffic in the centre (minimum width of 2.5m), and edge strips are marked by broken, reflective white lines on each side of the road way (SWOV 2013; Schermers and van Vliet 2001). The intention of the single traffic lane is to visually narrow the roadway, thus encouraging motorists to reduce their speed and travel toward the centre of the carriageway (SWOV 2013). If the carriageway exceeds 6.2m, or if the daily traffic volume exceeds 2,000 to 3,000 motor vehicles per day, the Dutch guidelines recommend constructing separated cycle ways (SWOV 2013).

Edge strips can be either a 'non-designated bicycle lane' with a width of 1.5m, or a 'designated bicycle lane' with a width of 1.5 to 2m (SWOV 2013). Both non-designated and designated bicycle lanes are marked with a broken white line 15cm in width, 1m long, and with a 1m spacing between lines (SWOV 2013). Non-designated lanes do not have legal status as a bicycle facility, and therefore motorists may drive and park in them. Designated lanes do have legal standing as a bicycle facility and so motorists may enter them to pass an oncoming vehicle, but must not stop in them (SWOV 2013). Designated bicycle lanes are coloured red and are marked with a painted bicycle symbol every 500m and after every intersection (SWOV 2013). Figure 2.11 shows designated bicycle lane edge strips being used by cyclists on a Dutch rural access road. Figure 2.12 also shows designated bicycle lane edge strips paved with brick on a Dutch rural access road, this time with bollards and a speed cushion, and lines of evenly spaced trees at the road edge, to slow traffic on a straight stretch of road.

Figure 2.11 Designated bicycle lane edge strips being used by cyclists on a Dutch rural access road

Source: Schermers and van Vliet (2001)

Figure 2.12 Designated bicycle lane edge strips paved with red brick on a Dutch rural access road, this time with bollards and speed cushion, and lines of evenly spaced trees at the road edge

Source: Schermers and van Vliet (2001)

Intersection treatments for rural access roads

In the Dutch system, intersections between access roads and higher-speed roads must be controlled and roundabouts are the preferred method. Alternatively, the lower priority road can yield (give way) to the higher priority road using a priority controlled intersection, with each contributing road being slowed to 40km/h through use of a raised 'plateaux' 50 to 100m before the intersection (Schermers and van Vliet 2001). Intersections between two access roads can be uncontrolled, or controlled via raised intersections, mini-roundabouts, or other speed calming measures. Where such intersections have important or high-volume cycle routes, they should be priority controlled with cycle traffic having priority (Schermers and van Vliet 2001). Figure 2.13 shows a roundabout at the junction of two 60km/h rural access roads in the Netherlands.

Figure 2.13 A roundabout at the junction of two 60km/h rural access roads in the Netherlands

Source: Schermers and van Vliet (2001)

Dutch guidelines state that rural access roads should be designed to cater to local traffic, and as such, should not have destinations signposted. Instead, street names can be signposted, and road side maps of the area can be provided. However, the guidelines also state that cycle routes through the area should be signposted (Schermers and van Vliet 2001).

Transition treatments for rural access roads

The Dutch also have specific guidelines for the design of the entranceway to a 60km/h rural access road, whereby road users must be made aware that they are entering a speed restricted area intended for use by local traffic (refer to figure 2.14). Measures to demonstrate this include using one or more of:

- posted speed limits
- a series of white transverse lines across the roadway
- the use of bollard ‘gates’ at the road edges to narrow the roadway
- the use of chokers to demarcate edge strips
- speed bumps and cushions.

Figure 2.14 Measures used in the Netherlands to transition to a 60km/h rural access road, including bollard 'gates', posted speed limits, transverse road markings, roadway narrowing, and a speed bump

Source: Schermers and van Vliet (2001)

Summary of the Dutch approach for rural access roads

Table 2.4 provides a summary of the approach used in the Netherlands to improve cycle safety on low-volume rural access roads.

Table 2.4 A summary of the purpose, application and measures used to improve cycle safety on low- volume, narrow, rural access roads in the Netherlands

Purpose	• Visually narrow the roadway to: - lower motor vehicle travel speeds - encourage motorists to take a more central lateral positioning, thus allowing more space on the road sides for cyclists.
Application	• Low-volume (max 3,000 daily traffic volume) rural roads used by cyclists.
Summary of midblock measures	• Speed limit of 60km/h implemented • Centreline removal • 1.5m wide cycle edge strips on each side of the road, marked by broken white line (may be a 'suggested' or legal cycleway) • If legal cycleways are marked, red surfacing and bicycle symbols are used, and the space is between 1.5–2m wide.
Summary of intersection measures	• Access roads intersecting higher-speed roads: - must be controlled - roundabouts preferred - give-way controls can be used with traffic calming measures (eg a plateau). • Access roads intersecting access roads: - can be controlled or uncontrolled - should implement traffic calming measures - on important cycle routes, cyclists should have priority.
Summary of transition measures	• Posted speed limits • Transverse lines • Physical obstacles

The effect of edge strips on Dutch rural access roads

A potential benefit of the Dutch use of edge strips on rural access roads is that it gives motorists more space to correct steering errors which may reduce the occurrence of vehicles leaving the roadway. In this case, damage to road shoulders may also be reduced along with the associated maintenance costs (SWOV 2013).

The Dutch have conducted a case-controlled before and after study on the effect of reducing the speed limit on rural access roads from 80km/h to 60km/h. Their findings show that crashes resulting in casualties (fatalities or injuries) were significantly reduced by one fifth (Beenker 2004 in SWOV 2013). However, this study included roads where edge strips had been implemented, as well as roads without edge strips, and as such, this report concludes that it is not possible to know what contribution edge strips made to the reduction in casualty causing incidents (SWOV 2013).

Van der Kooi and Heidstra (1999) reported that motorists on roads with edge strips travelled slower than those on roads without edge strips. However, this study found that motorists travelling on roads with edge strips passed cyclists with slightly less lateral distance than vehicles travelling on roads without edge strips. In a more recent before and after study on the effect of edge strips, Van der Kooi and Dijkstra (2003) found that cyclists tended to stay in the strip and travel further from the road edge. Motorists also tended to travel further from the road edge. This study also found that the overtaking distance between cyclists and motor vehicles was slightly reduced (by a few centimetres) by the introduction of edge strips, as drivers tended to avoid travelling in the edge strip on the opposite side of the road when passing cyclists. However, this study also found that average driving speed was reduced by a few km/h with the introduction of edge strips. A meta-analysis of studies found that the addition of edge strips to a road could result in small, but significant, mean speed reductions of about 2km/h (Davidse et al 2004).

In a road user perception study, Aarts and Davidse (2007) reported that edge strips coloured red were especially recognisable, and created an expectation among road users that cyclists may be present (SWOV 2013).

A more recent study by Jaarsma et al (2011) examined the road safety effects of the 60km/h speed limits and physical traffic calming measures on Dutch low-volume rural roads. Road safety in 20 areas was studied for five years before, and for three and a half years after treatment. Control sites were low-volume rural roads with 80km/h speed limits and no physical traffic calming measures. The results from this study show that midblock causality crashes reduced by 25% on treated roads, and intersection causality crashes reduced by 44%. The authors found that the cost-effectiveness of 60km/h speed limits and physical traffic calming measures on Dutch low-volume rural roads was €33,000 per prevented killed or seriously injured casualty, which is two and a half times more cost effective than the traffic calming measures used in Dutch urban areas.

2.4.3.2 International application of Dutch edge strips

Norway

In a Norwegian evaluation study by Erke and Sorensen (2008), Dutch-style edge strips were reviewed for rural roads with a speed limit of 60km/h or less, where centrelines were removed and edge strips were introduced. This evaluation found that edge strips encouraged cyclists to move toward the centre of the road, but motorists did not shift their position, resulting in a reduced distance between bicycles and motor vehicles. It was also found that motor vehicle traffic on some of the treated roads had reduced, and the authors suggest this traffic may have moved onto the main road.

Perceived road safety for the majority of cyclists in edge strip trials was low both before and after the edge strips were introduced (Erke and Sorensen 2008). Additionally, a survey of motorists found that while most drivers stated they knew how to drive on this edge strips layout, when tested on the correct behaviour there was a low level of understanding (‘almost none’) as to how to negotiate other vehicles. The main conflict stated by motorists was not knowing who should give way.

The authors proposed two potential reasons for the result of these trials. First, cyclists may think that the marked edge strip is a cycle lane and not expect motor vehicles to enter it. Second, motorists may expect that cyclists have to give way. The authors suggest that, to improve the effect of edge strips, other measures can be included such as:

- speed limits and enforcement
- physical measures that are cycle friendly, such as speed bumps and road narrowing
- lighting.

The authors also suggest that it may be desirable to trial a rural application of shared space arrows, also known as “sharrows” (symbols indicating an area is a shared space zone for motor vehicles and cycles, comprised of a profile image of a cycle and two chevrons above this pointing in the direction of travel).

This provides a good evaluation of trials of Dutch edge strips that did not appear to be successful, which means there may be important lessons here if Dutch edge strips are to be employed in New Zealand. It appears that the failure may come down to two factors:

1 The edge strips were applied in isolation, no other measures were implemented.

2 Road users do not appear to have been educated on how to use the new road layout.

Any implementation of the Dutch system in New Zealand would require these factors to be addressed.

The UK and the USA

The UK’s cycling advisory body (now abolished) recommended centreline removal and the use of 1.5m wide cycle ‘advisory strips’ on narrow roads (Cycling England no date). No literature was found documenting the use or effect of advisory strips on low-volume rural roads in the UK.

Furth (2009 and 2011) trialled the use of Dutch edge strips with sharrows for use on shared lanes in three cities in the US and found some cyclists shifted laterally toward the centre of the lane. However, there does not appear to have been a trial on rural roads in the US.

New Zealand

A New Zealand application of Dutch edge strips and removal of the centre line has been installed on Tuki Tuki Road, Hawke’s Bay, outside of Havelock North on a popular cycling route, known as the Twin Bridges Ride (refer to figure 2.15). This New Zealand application has relevance as it applies the Dutch approach. This installation involved road widening and removal of the centreline on straight sections of road. The road cross section is 1.5m shoulders, solid white edge lines and a 5m traffic lane. The shoulders are marked as cycle lanes with the bicycle symbol. The improvements were installed in 2011 and there is no published review of their performance. Discussion with Hasting District Council staff suggests there is some before and after speed count data and limited cycle count information. The installation complies with current New Zealand traffic control devices regulations (NZ Transport Agency 2008), but is unique in New Zealand. The Tuki Tuki Road project was installed as part of the ‘i-way model community project’. Discussions with local cyclists identified that a key limitation with this Hastings layout was the debris build-up on the shoulders, which was not swept clean by traffic. This was because the existing central 5m traffic lane was wide enough for two vehicles, so vehicles did not travel over the shoulder when passing.

This meant that it was common for cyclists not to ride on the shoulder, but instead ride just outside the white line in the narrow two-way traffic lane.

Figure 2.15 Tuki Tuki Road Hawke's Bay looking north, showing no centreline 2- 1 layout

2.4.3.3 UK approaches

Quiet lanes

The UK has trialled the introduction of 'Quiet Lane' networks in Norfolk and Kent. For this trial, 99km of narrow (less than 5m wide), minor rural roads with low traffic volumes (less than 1,000 average annual daily traffic (AADT)) and low speeds (85th percentile less than 56km/h) were treated to make them more appropriate for shared use. The aim of Quiet Lanes was to restrict future traffic growth on these quiet roads, and to encourage through-traffic to shift to main roads (DfT 2004).

The first step in creating Quiet Lanes was to engage and involve the local community throughout the process. This was seen as the key mechanism to encourage change. A slogan was created for quiet lanes, 'share with care and be aware', to increase motorists' expectation that they would encounter people walking, cycling or riding horses. Quiet Lanes were publicised via exhibitions, the media, leaflets and meetings. Local stakeholder groups participated (councils, churches, businesses, emergency services, schools, pubs, hotels and other interest groups).

Area wide signage was created in order to re-route traffic away from Quiet Lanes. Distinct signage was created and provided for walkers and cyclists. These signs advised users that they were entering a different type of road and a shared space, and were designed to look different from traffic signs. The majority of locals approved, but thought they were too inconspicuous. Signs are now made twice as large.

Establishing Quiet Lanes did not include setting speed limits or employing significant traffic calming. Minor traffic calming was used which included:

- Transverse rumble strips (designed to resemble a cattle strip). Initial results show one direction had a 6.4km/h reduction in speeds, with longer-term reductions of about 3.2km/h. The other direction had no significant change in speeds.

- A pink coloured road surface with uneven edging was used to make the road appear narrower. No speed measurements were taken for this site.

Average speeds before the trial were relatively low (about 50km/h, and 85th percentile speeds were about 57km/h) and there were no significant changes in speed before or after compared with the control sites. Traffic flows before the treatment were around 2,000 AADT. There was a reduction in motor vehicle traffic compared with the control sites, with an average of 8% to 17% reduction on weekdays, and a 1% to 23% reduction in weekends. Flow and speed monitoring was undertaken on straight sections of the road, so it is not known if speeds reduced more significantly at corners.

User perception surveys were carried out via focus groups, road user surveys, postal and telephone questionnaires, and surveys at local attractions and amenities. An average of 16% of people reported that they were now more likely to use the lanes for walking, cycling or riding horses, and over three quarters of residents supported the initiative before and after. However, people perceived that it had not worked citing traffic speeds and motorists using the lanes as short cuts. Between 40% and 50% of local residents reported they now drove more carefully along the Quiet Lanes. Crash rates were low before and after and, as a result, no significant effect on crash rates was found (DfT 2004).

General traffic calming on rural lanes

As demonstrated in a review of practice by Dorset County Council (2005), traffic calming on local rural lanes is common in the UK. Although most of these measures remain largely unevaluated, their stated intention is primarily to retain the use of rural lanes for local use, as well as for people walking, cycling and riding horses. Other than the creation of Quiet Lanes and centreline removal, a range of other measures are practised. For example, in Devon, a local road hierarchy has been created whereby different roads have different functions, and each type of road is colour coded on both signs and maps. The content of signage is important and through-traffic is encouraged to use main routes rather than rural lanes. Other measures widely used include retaining the original condition of country lanes, such as vegetation, alongside the road and at intersections, and retaining or reinstating sharp bends and narrow carriageways. The Countryside Commission recommended against the use of specific signage and road markings for cyclists as it might reduce motorists' expectation of encountering cyclists on other roads where such measures were not present (Dorset County Council 2005). While they do not cite evidence for this, this way of thinking is similar to the Dutch approach. However, what differs is how the Dutch overcome this by creating consistency and recommending the provision of cycle edge strip markings and signage on all low-volume rural roads on which cyclists may be present.

2.5 Measures of safety effectiveness

The success of alternative road layouts in improving cycle safety have been measured in studies (such as Herrstedt 2007; van der Kooi and Dijkstra 2003) by observing a range of objective and subjective factors, both before and after implementation.

The most commonly measured objective factors include observed changes in:

- vehicle speeds
- road user lateral positioning (distance from both road edge and from other road users)
- road user behaviour at intersections and when negotiating other road users
- changes in fatal and serious injury crash rates over a longer period of time.

Davidse et al (2004) stress that when assessing ‘before and after’ change in lateral positioning and vehicle speeds, it is important to examine both the mean and variance. Furth (2009) agrees, and adds it is also important to capture the frequency of cars that do not provide sufficient lateral space when overtaking cyclists.

Objective measures of cycle safety can be captured using stationary or moving (vehicle mounted) instruments, including cyclist mounted cameras and/or sensors (see for example Johnson et al 2010). In one such study, Walker (2007) used cyclist mounted cameras in suburban London to record how motorists' perceptions of a cyclist affected overtaking behaviour. This study found that motorists overtaking distance from the cyclist decreased when the cyclist: a) wore a helmet, b) rode closer toward the centre of the road, c) was male, and d) when the motorist was a truck or bus driver. A similar study tested different cyclist clothing types (suggestive of the cyclist's level of riding experience) on overtaking distances and found that in general, motorists ‘do not adjust overtaking proximity as a function of a rider's perceived experience’ (Walker et al 2014, p2). Although these are somewhat contradictory findings, these studies highlight that it may be important to evaluate motorists' behaviour when overtaking different types of cyclists.

Shackel and Parkin (2014) employed an instrumented bicycle to test the effect of road markings and widths on motorists' overtaking behaviour (passing distance and speed) when passing a cyclist on lower-volume urban roads. This study also measured the type of vehicles overtaking, the effect of oncoming vehicles, and whether the oncoming and overtaking vehicles were in a group or ‘platoon’, defined as ‘vehicles travelling within three seconds of each other’. Shackel and Parkin conclude that low-volume urban roads may better accommodate cyclists if speed limits are reduced, and if the centreline is removed when lanes are too narrow to allow safe passing within the lane.

Similarly, Chapman and Noyce (2012) conducted a cyclist mounted camera study in Wisconsin, USA, to observe motorist overtaking clearance on rural roads. This study found that motorists frequently overtook cyclists in a hazardous manner by crossing the centreline to overtake in areas of insufficient forward visibility, such as when approaching vertical and horizontal curves. Their study found that such behaviour was between four to six times less likely when the road had paved, marked shoulders. Their study also stressed the importance of monitoring whether the passing location was appropriate for passing.

For their analyses, Chapman and Noyce (2012) also recorded:

- location and direction of travel
- road conditions
- bicycle and vehicle speed, position and lateral clearance
- traffic rule violations, near misses and crashes
- weather conditions
- presence of oncoming vehicles (motorist or cyclist).

Perceived or subjective measures of safety and other attitudinal measures can also be used to assess cyclists' or other road users' comfort and satisfaction with the road changes (Sorensen and Mosslemi 2009). Such measures can be useful as they may capture the ‘why’ behind observations, reveal the presence of any confusion regarding the road changes, and can also capture near-misses.

2.6 Process for selecting trial treatments, measures and site location

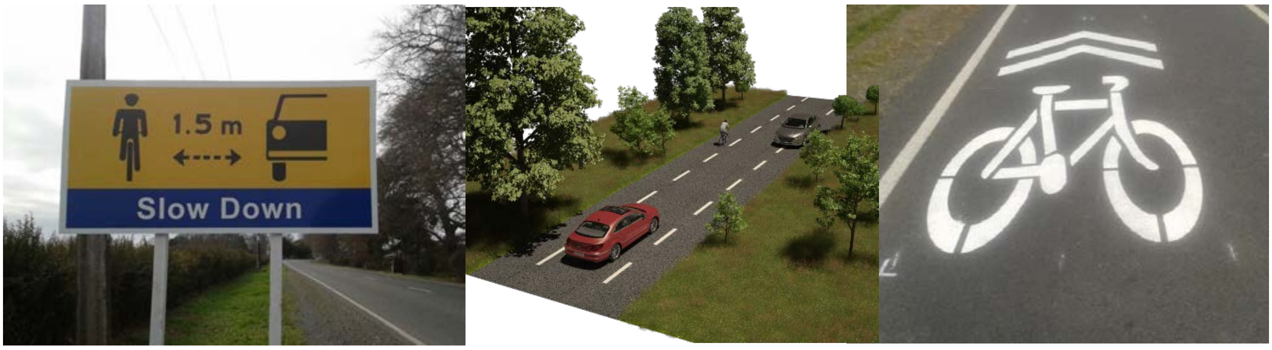
The review of road treatments was given to the Steering Group of experts who discussed the merits and limitations of the treatments, focusing on the benefits to cyclists, cost-effectiveness, and acceptability to road controlling authorities (RCAs) and motorists. Four treatments were then short-listed for trial, as follows in order of preference:

1. **2-1 design:** Implementing a 2-1 design layout (with two road shoulders for cyclists and one shared lane for motorists with no centre line marking), adapted for a New Zealand driving environment.
2. **Advisory speed and distance treatments:** Using advisory speed and distance signage for motorists, to encourage safer overtaking behaviour when passing cyclists. It was agreed the 1.5m passing width was a key element, as there was perceived to be a low understanding of this where it had already been implemented in high-speed motoring environments.
3. **Rural cycle route signage:** Using a range of signage to raise expectations of cyclist presence (eg using existing NZ Cycle Trail Route devices) and clearly brand rural cycle routes.
4. **Road shoulder surface treatments:** Improving road shoulder surfacing, maintenance or colouring.

After receiving feedback from the TCD Committee and formulating more detailed design decisions, the pool of treatment options was further refined to the following trial conditions (see also figure 2.16):

1. 2-1 layout (adapted to New Zealand roads), including rural sharrows on curves and a 60km/h speed limit. A separate condition was created for a baseline 60km/h speed zone prior to the 2-1 layout to isolate any additional speed change from the speed zone condition to the combined 60km/h speed zone condition with 2-1 design layout.
2. Advisory signs on passing distance.

Figure 2.16 Trial condition visuals



Advisory distance signage | 3D image of 2-1 layout | Sharrow (shared space arrow)

2.6.1 Design consideration rationale

Further discussion of each treatment condition led to more detailed treatment considerations. The points below outline some of the design considerations (which may have relevance for similar trials in the future).

2.6.1.1 Advisory distance signage

The signage option developed for the site consisted of an image of both a cyclist and motorist with the specific distance (1.5m) indicated in the space between the two (see figure 2.16, left). This is based on the distance recommended by the Transport Agency's Cycling Safety Panel, and both the distance and sign layout is similar to that now legislated for South Australia, Queensland and Australian Capital Territory. The colouring (yellow top panel, blue below) is consistent with the high-risk motorcycle area signs that are also currently being trialled in New Zealand.

2.6.1.2 2-1 layout adapted for New Zealand

Speed limit: It was agreed the speed limit on a 2-1 layout should be set to 60km/h, primarily due to the crash benefits to cyclists at this speed and the adoption of this speed in other 2-1 layouts (see section 2.4). This also aligns with the Transport Agency's one network approach to road classification, where there is shift towards lower speed limits on low-volume rural roads.

Use of cycle symbols: Cycle symbols were originally suggested for the shoulder. However, these symbols in New Zealand currently denote a legal cycle lane, which is essentially a cycle-only space. So it was deemed preferable to avoid using cycle symbols, as it was intended that, in the absence of cyclists, motorists use these shoulders when passing other motorists. There was concern that motorists would be hesitant to use the shoulder because of the symbol's association with cycle-only lanes.

Shoulder width: There was some discussion on making the width 1m to 1.2m, due to concern around a limited 3m centre-lane space. In the end the final decision was based on the overseas recommendation for a 1.5m shoulder (edge strip) for a 'non-designated bicycle lane' (SWOV 2013).

Shoulder line marking: There was a preference for the 2-1 marking to be a broken line rather than a continuous line. A dashed line was perceived to be more permeable (and is in line with overseas examples). The existing use of a dashed line marking in New Zealand implies you can cross the line when it is clear to do so (eg a centre line). This also removes similarity to cycle lanes, which have a solid separation line between the cycle lane and traffic lane. Experts raised the issue that motorists may feel hesitant to enter the road shoulder under a new layout and the dashed line may make them more comfortable. A secondary element was that a dashed marking would use less material, so would result in some savings. A more general limitation raised was that a solid line provided a better delineation environment to negotiate road curves during limited visibility conditions (such as at night). However, as the markings would be laid on straight road locations, this was perceived to have low impact.

Shoulder treatments: As shoulder treatments had been short-listed for trial, the options were discussed in greater detail. It was decided that more frequent maintenance scheduling would be of greatest benefit, given that a common finding was for cyclists to ride on the shoulder line or in live traffic due to debris on the road shoulder. A colouring treatment (such as the use of a green colour) was perceived to be a high cost for local RCAs on a low-volume rural road. This perception held even when intermittent colour use was suggested (eg a brief 5m long colour refresh every 500m), as has been done on other New Zealand roads.

Awareness, education and information: Several mail drops to the local community in the vicinity of the on-road site and through the local school were made in order to raise public awareness of the trial of an intervention aimed at improving the shared road design for motorists and cyclists.

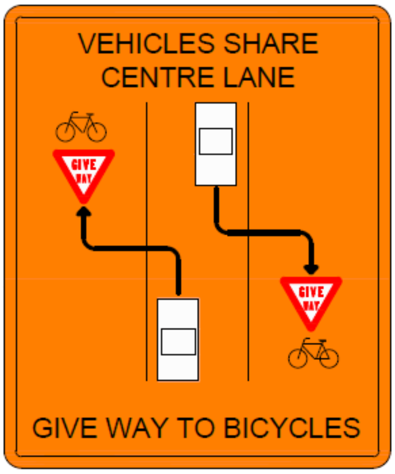
One element debated at great length was how much information to provide road users. There was a concern to educate road users of their rights and responsibilities when using a new layout, particularly:

- how and where motorists should overtake cyclists
- who must yield.

The benefit of a high level of information was a stronger understanding of the layout and correct behaviour. Conversely, a low level of information would provide a better understanding of whether the design was intuitive in a New Zealand setting. It was also suggested that it was necessary to limit the level of education for the purposes of this investigation, as overly explicit information was perceived to reduce experimental control. For example, it might not be clear whether a change in motorist behaviour was due to the treatment or education variables.

Figure 2.17 shows an example of behaviour-based signage demonstrating a visual example of correct behaviour that was put forward for consideration. It was derived from signage already used in the US (Hanover Department of Public Works 2013; City of Banks 2015).

Figure 2.17 An example of behaviour-based signage for the 2-1 design



Other signage that was considered but not used included designs that were more in line with existing advisory signage used at new road layout sites (such as road work sites; see figure 2.18).

Figure 2.18 Treatment signage used to inform drivers of the upcoming 2-1 design

The final signage used can be seen in figure 2.19, simply reminding drivers of the reduced speed environment and warning drivers of the upcoming change to the road layout to raise their level of alertness. See also chapter 6 for more about an intuitive approach to new layouts in the future.

Figure 2.19 Treatment signage used to inform drivers of the upcoming 2- 1 design

2.6.1.3 Rural sharrows – an additional trial recommendation

A key issue in the translation of the 2-1 layout for New Zealand conditions was the difference in geography (compared with many European countries, such as the Netherlands, where flatter terrain is more common). With hilly terrain, it was deemed necessary to trial a solution that would resolve any conflict between cyclists and motorists at horizontal or vertical curves (where sight distances to cyclists may be limited). This was also extended to intersections. In a study in Wisconsin, Chapman and Noyce (2012) also identified poor overtaking behaviour by motorists in rural settings when overtaking cyclists in areas with insufficient forward visibility.

Therefore, the 2-1 layout was not continued in sections of road with vertical or horizontal curves or at intersections. To provide route continuity and a proactive safety improvement at these locations, a sharrow marking was identified as an appropriate solution (combined with the use of a centre line). Sharrows were selected as they had been introduced and tested in a number of urban New Zealand locations (ie Wellington, Dunedin and Auckland). Research in this area had found that sharrows had little effect on cyclist behaviour, but that cyclists did feel a greater sense of belonging on the road and felt that motorists gave them greater lateral distance when passing (eg Trotter et al 2015). More importantly, however, research showed that the presence of sharrows significantly decreased motorist speed, although road users (both cyclist and motorist users) often were not aware of such reductions. There was also some evidence that further education and awareness would be helpful in enhancing driver and cyclist understanding of their meaning.

It was agreed that the sharrow be placed 200mm from the road edge in the live traffic lane to: 1) indicate the safe path for cyclists to travel, and 2) encourage drivers to look for and expect cyclists in this location and provide cyclists with space.

2.6.2 Process for selecting performance measures

Based on the Steering Group's feedback, the methodology also shifted from fixed cameras to instrumented cycles, primarily to increase the number of cyclist–motorist interactions and gain a better picture of motorist behaviour when approaching cyclists. The shift in methodology to developing prototype instrumented cycles meant additional resource costs that caused some constraints on the scope of the overall project (such as the removal of a perception study looking at subjective impressions of the designs). For more information on the measures see section 3.1.2.

2.6.3 Process for selection of possible trial locations

The selection of trial locations began by addressing the following questions:

- Where are local authorities amenable to a speed limit reduction?
- Where are the most popular/highly used cycle routes? (This may or may not be NZ Cycle Trail routes.)
- What is the road width, topography and geometry of low-volume (AADT being less than 3,000) rural roads in the area.

Eight different RCAs were asked if they were interested in being involved in this road research project: Auckland City, Northland District Council, South Waikato, Rotorua District Council, South Waikato (Waipa District Council), Hastings District Council, Taupo District Council and New Plymouth District Council.

It was the preference of the Steering Group to look more closely at a possible trial site in either Hastings District or Waipa District, based on key information, including that these are areas of cyclist activity (and perhaps consequently) rural crash hot spots. Hasting District was a Transport Agency model community area where many cycling infrastructure projects were being implemented, including a wide road 2-1 design. Waipa District had a high interest in cycling with a new Avanti Velodrome and it was an emerging national hub for road cycling. After discussion with both councils and site visits, it was decided to select a trial site in Waipa District – Roto-o-Rangi Road – just outside Cambridge between Leamington and Te Awamutu. Roto-o-Rangi Road was chosen because it had low traffic volume (traffic volume < 1,000 AADT, so it is classified as a rural secondary collector road on the Transport Agency's road hierarchy, One Network Road Classification (ONRC)[1]), has rural surrounding land use, is an existing cycle route, does not have an existing cycle crash history, and has a varied alignment with suitable length straights for a 2-1 layout. The cycle volume along this route has not been recorded but it is estimated to be in the range of 10 to 50 cyclists/day depending on local cycle club team rides (see section 3.1.4).

[1] Refer www.nzta.govt.nz/roads-and-rail/road-efficiency-group/one-network-road-classification/

3 Method

3.1 On-road trials

On-road trials were conducted to determine the effectiveness of road treatments in encouraging appropriate driver behaviours thereby enhancing cyclist safety. The on-road methodology allowed measurement of naturalistic driver responses. The purpose of this phase was to objectively measure driving behaviour in response to the treatment options in a real-world setting.

3.1.1 Experimental treatment design layout

Following the literature review, CAS analysis, Steering Group feedback and feedback from the TCD Committee, two treatments were identified and developed for the purpose of this trial:

1. Advisory signs on passing distance
2. 2-1 layout (adapted to the New Zealand context), including rural sharrows on curves and 60km/h speed limit.

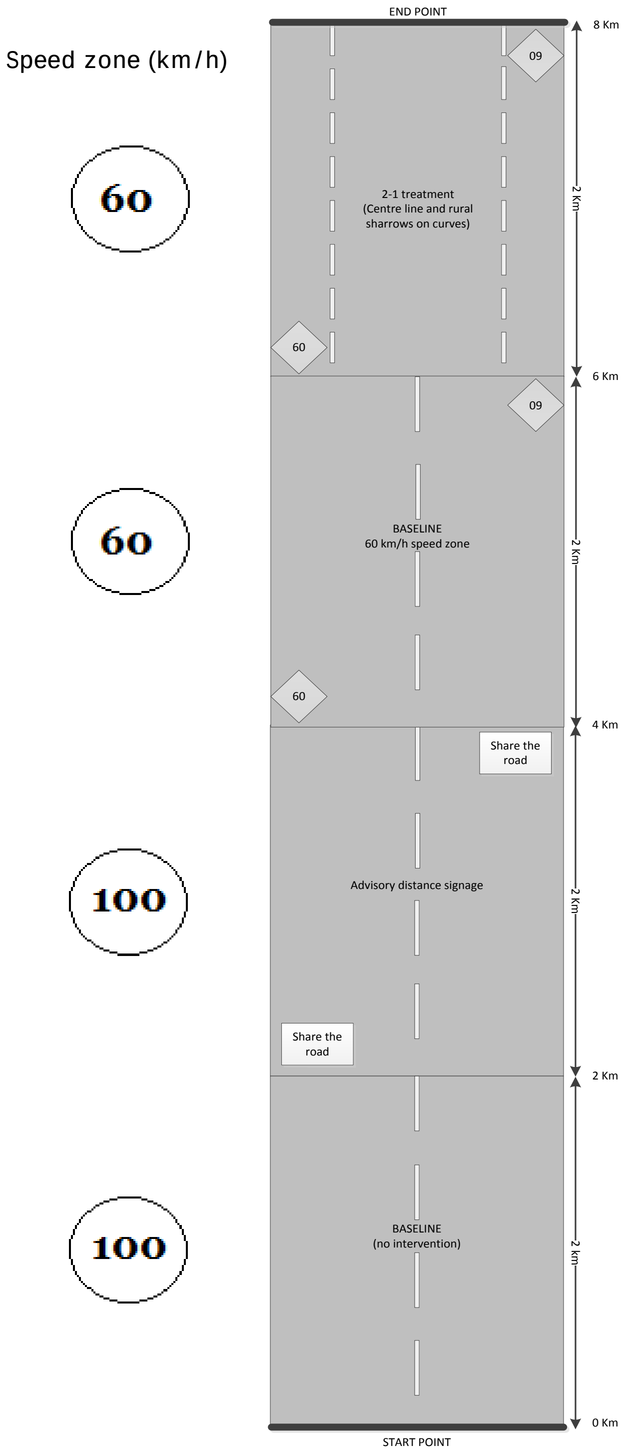
These treatments were designed to build upon each previous treatment, with the advisory signage, speed treatment and finally the 2-1 layout. It was done in this sequential order to ensure the 2-1 was not implemented in isolation, so that road users were warned of upcoming changes to the road layout, but also slowed down in advance of this new treatment. For real-world safety reasons it was always expected that the 2-1 would be complemented with signage and speed treatments. Only one change was implemented in each new treatment condition, to ensure the additive change related to each treatment was captured in isolation. For example, any speed change from the 2-1 design was isolated from the 60km/h speed zone change. The trial section used four two-kilometre sections along an 8km section of road (see figure 3.1). The conditions in order were:

1. Baseline (100km/h)
2. Advisory signage (100km/h)
3. Advisory signage and speed treatment (60km/h)
4. Advisory signage, speed treatment (60km/h) and 2-1 layout.

Design philosophy for the 2-1 layout

The New Zealand application of a 2-1 layout converts a standard two-lane rural road into a narrow shared traffic lane used by two-way traffic of 3m to 4m width, with 1.5m shoulders and 60km/h speed limit. The traffic can travel down the road using the central lane and when they encounter on-coming traffic they use the shoulder area to pull to the left and pass the on-coming vehicle. The vehicle use of the shoulder also sweeps the shoulders and maintains clear of debris. Rural cyclists use the provided shoulder to cycle safely along the road section. Motorists travelling along the road without oncoming traffic should use the central lane unimpeded. If a motorist encounters an oncoming vehicle and there is a cyclist riding in the shoulder, then the motorist is required to reduce speed and follow behind the cyclist until its way is clear to continue.

Figure 3.1 Indicative road layout for four treatments



3.1.1.1 2- 1 on- road layout design

Careful liaison was undertaken with the Transport Agency's TCD Committee representatives on the layout, line types, speed limit and temporary advance warning signage adopted for the 2-1 layout. It was agreed that the a 2-1 layout was legal under current traffic regulations, as there is no requirement for edge lines to be solid and continuous, nor is there any requirement for a centreline or minimum two-lane carriageway width. The 2-1 marking layout can be seen on Roto-o Rangi Road in figure 3.2 and the final implementation design layout plan is shown in figure 3.3.

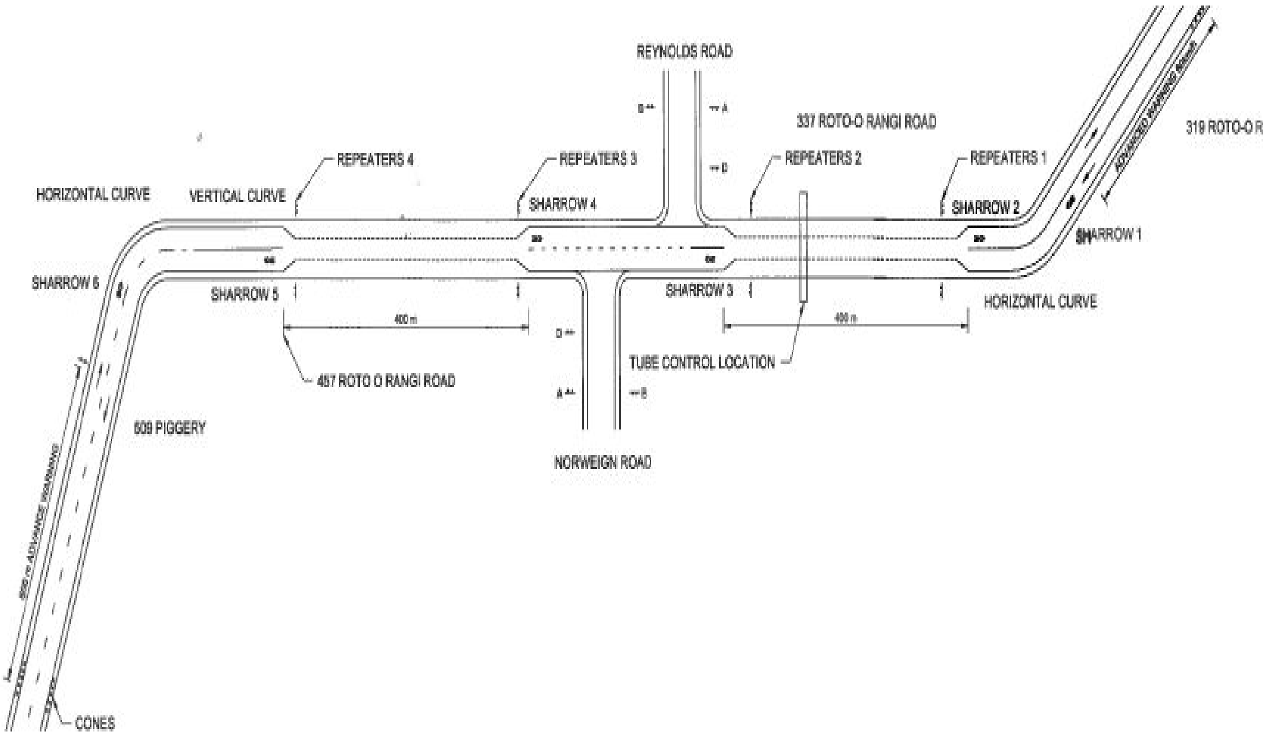
Figure 3.2 2- 1 layout on Roto- o- Rangi Road

The agreed site 2-1 implementation format had the following features (see section 2.6.1 for more on the rationale behind these decisions):

- 60km/h speed limit (consistent with similar speed limits used internationally from the literature research). Repeater 60km/h speed signs were installed throughout the site at 400m spacing.
- Warning signage highlighting a new road layout ahead (similar to new layouts at road work sites).
- No centreline, 1.5m shoulders and a 3.6m central lane.
- Dashed white edge lines (consistent with international layouts) for the purpose of encouraging overtaking using the shoulder. The line type was a 100mm wide, 2m long painted solid white reflectorised line, with a 2m gap to make it distinctly different from a centreline or continuity line type.
- Tourist painted direction arrow at the end point of each 2-1 section to ensure motorists return to the correct side of the road.
- 2-1 layout was not continued around vertical or horizontal curves or continued through intersections.
- Every side road had similar signage through the trial section. The lead into each section had the following temporary traffic management approach signage sequence:
  - T2A/T211 exclamation sign with new road layout sub-plate
  - TW-special sign with cycle symbol, TS/TG-1(60) 60km/h speed reduction signs

- In each section where the 2-1 was removed (horizontal and vertical curves) rural sharrows were installed to provide a consistent route treatment. The rural sharrow was positioned 0.5m from the edge line to indicate the actual likely position of a cyclist. These were on horizontal and vertical curves and through intersections.
- The two sections of two 2-1 were along two 400m straights (with a similar 300m gap between the two sections where there was a vertical curve combined with two side-road intersections).

Figure 3.3 A map of the 2- 1 layout Rural Cycle Safety Plan

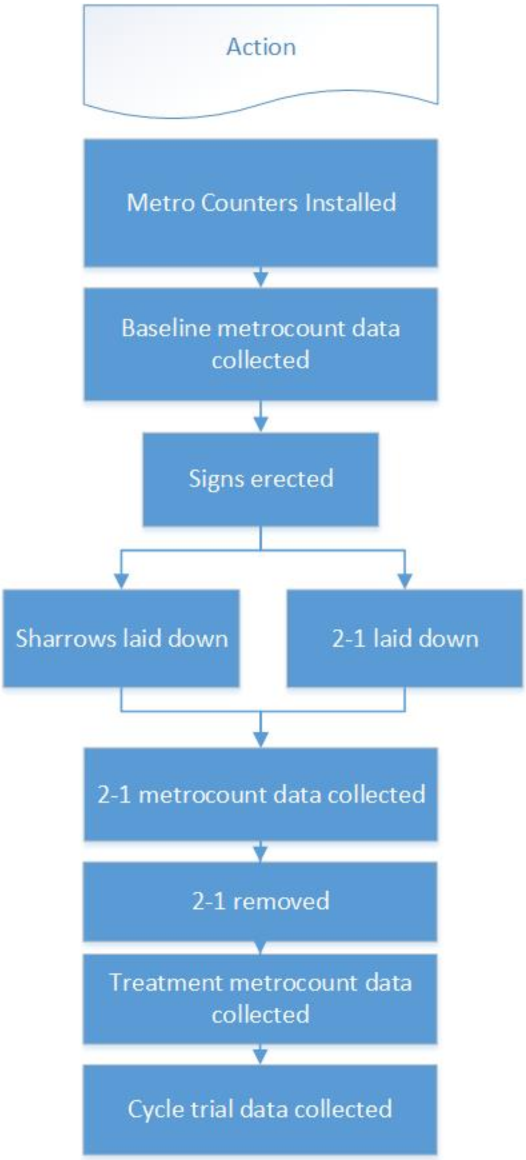


3.1.2 Treatment implementation

The road treatments (billboard signs, speed advisory signs, 2-1 road layout and sharrow markings) were in place from 23 July 2015 (see figure 3.4).

Prior to implementation the Transport Agency and Opus worked in conjunction with the local council and carried out several letter drops to the local community in the vicinity of the on-road site and through the local school in order to raise the public awareness. The 2-1 layout was also preceded by signage indicating a new road layout and a drop to a single lane. However, the specifics of exactly what the road-markings and signs would require of the motorists was not explicitly stated in the letter, in-part in an effort to avoid priming effects (ie motorists altering their behaviour prior to their direct exposure to the treatments). See also section 2.6.1 for more on the rationale behind the approach.

Figure 3.4 Timeline showing the experimental treatments and monitoring periods



3.1.2.1 Removal of the 2- 1 treatment

Installation was monitored by the project manager who observed motorist and cyclist behaviour. After 24 hours of monitoring, the decision was made to remove the 2-1 component of the trial for the safety of motorists and cyclists. A key factor in this was that motorists did not reduce their speed to the signed 60km/h at night. Other contributing factors included the occurrence of a potential incident, together with public feedback (from public complaints to Waipa District Council). The potential incident related to oncoming vehicles. One driver swerved left and braked heavily, coming to a sudden stop on the road shoulder. A following vehicle attempted to overtake this stationary vehicle and created a potential conflict with another oncoming vehicle, as there was insufficient width for two vehicles to pass with this third vehicle stopped on the shoulder. Despite the removal of the 2-1 markings, the findings in sections 4.2 and 4.3 indicate that this design is worthy of further investigation. Similarly, some suggestions and lessons learnt from this trial are also offered to mitigate these issues in any future 2-1 trials (see chapter 6).

3.1.2.2 Revised experimental treatments

Upon the decision to remove the 2-1 layout, road markings were immediately returned to their original state (suggestions lanes removed, centre line reinstated). The temporary speed reduction signs were also removed and the speed limit returned to the original 100km/h. This left the following treatments in place (see figure 3.5):

- baseline (2km)
- advisory signage (4km – includes section that was previously 60km baseline; see figure 3.6)
- sharrow markings (2km – previously 2-1 + sharrows; see figure 3.7).

The sharrow markings were placed in both directions meaning that, for this section, interactions in both directions could be included in the analysis.[2] Interactions from both directions of the baseline section of the cyclist route were also included in order to increase the sample size.

[2] Note that on the southward bound leg of the route, there was an uncovered cycle sign – meaning that the sign could have been affecting the motorist's behaviour on that stretch of road, confounding the effects of the treatments. Therefore, the data between this sign and 1km of road south from this sign were excluded from all analyses.

Figure 3.5 Final trial road layout (all 100km/h speed zone)

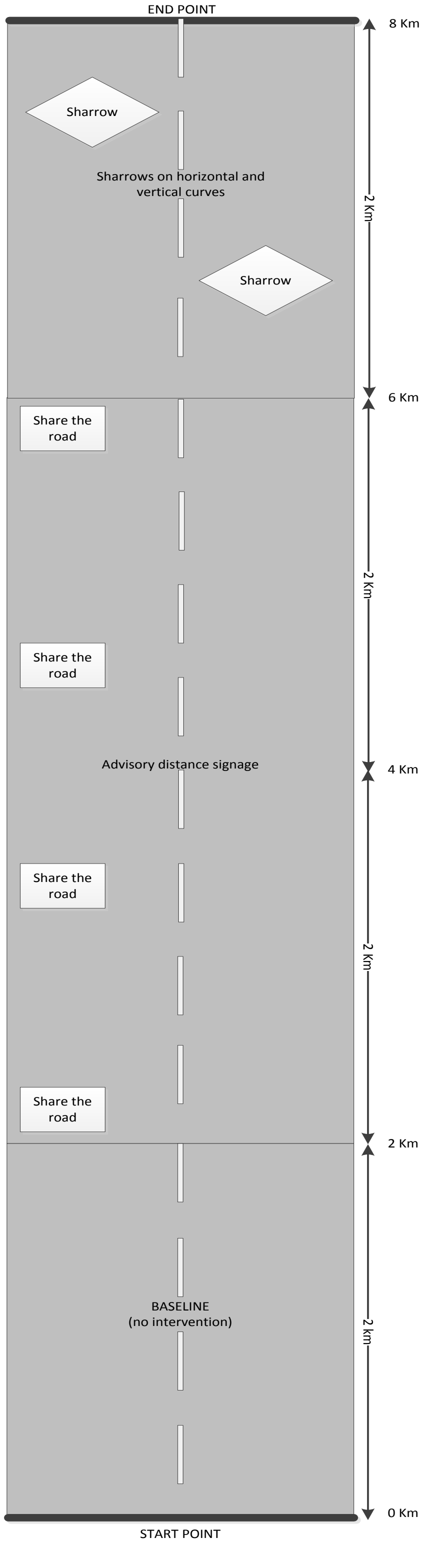


Figure 3.6 Advisory distance signage used in on- road trial

Figure 3.7 Sharrow markings used in on- road trial

3.1.3 Road treatment performance measures

The performance of the road treatments was measured in real-world settings to ensure ecological validity. Motorist behaviour was observed naturalistically, using key performance measures. The specific objective measures of effectiveness, as informed by the literature review, were:

- approach speed (of passing vehicle)
- passing distance (distance from cyclist to vehicle)
- bicycle speed.

Position on the route was also measured. Cyclist and motorist data was obtained using an integrated suite of instrumentation on four bicycles (see figures 3.8 and 3.9). The key rationale behind an instrumented cycle approach (as opposed to a fixed environmental observation approach) is made based on expert review and Steering Group comments in order to first, maximise cyclist–vehicle interactions, and second, to ensure motorist behaviour was naturalistic. The instrumentation included:

- an ultrasonic device to capture the lateral separation distance or gap between cyclist and the vehicle as it passed
- a radar device to capture the speed of the vehicle as it approached
- a rear-facing camera to capture motorist behaviour as it approached
- a GPS unit to determine cyclist speed and position on the route.

Figure 3.8 Instrumentation attached to bicycle for on-road study

Figure 3.9 Inside of instrumentation box used in on-road trials

Metrocounts were installed at two sites along the route, one at 372 Roto-o-Rangi Road, in the centre of the sharrow treatment area; and the other at 757 Roto-o-Rangi Road in the signage treatment area (see figure 3.10). Average free-flowing vehicle speed was measured for the period prior to and during the treatment periods.

3.1.4 Location

The route selected for the on-road trial was located in the Waipa District near the outskirts of Cambridge (near Hamilton in the North Island of New Zealand). The route ran along Roto-o-Rangi Road from the intersection of Parklands Road to the intersection of Settlement Road (see figure 3.10) and was a 100km/h speed limited area. The route was selected with the assistance and support of Waipa District Council. It is a relatively low-volume rural road (AADT <1000), popular with local cyclists for training and recreational rides, and has operational driver speeds below 100km/h.

Figure 3.10 Map of Roto- o- Rangi Road trial route

3.1.5 Participants

Cycling participants were recruited from bicycle clubs and local contacts in the wider area using a convenience sampling approach. The recruitment process encouraged a mix of rider gender and age. Participants were provided vouchers to acknowledge their time and effort. A total of 11 participants were recruited:

1 Gender: Six males, five females

2 Average age: 47 years (SD = 10.9: 30–65 years)

3 Experience (self-reported):

   a six expert

   b four intermediate

   c one novice.

Motorists were those observed on the route at the time of the trial. The trial was conducted between 10.30am and 3.30pm on Saturday 3 October 2015. The time of year was chosen as it increased the likelihood of adequate weather conditions (ie no rain), as this may have interfered with the equipment as well as cyclist behaviour. The time of day was chosen in order to maximise the number of motorists using the route, and hence the number of cyclist-vehicle interactions.

3.1.6 On-road trial participant procedure

Participants arrived in the morning at Roto-o-Rangi School, located on Kairangi Road. This was the base for the project team and was in the centre of the test site. Each run of the trial route consisted of a circuit running from Parklands Road, up Roto-o-Rangi Road, a turnaround at Settlement Road and then a return back to Parklands Road. If participants were tired, they swapped with another rider at the mid-point of the circuit at Kairangi Road. Six participants were selected to ride in the first run. Of these cyclists, four of their bicycles were fitted with the instrumentation and calibrated ready for the commencement of the trial. Two instrumentation boxes were fitted to bicycles of riders who would ride as part of a pair (the other cyclist in the pair rode a non-instrumented bicycle). Paired riders were instructed to stay together and ride either two abreast or single file as they felt comfortable. The paired riders were instructed to ride with the rider of the instrumented bicycle closest to the centre line when riding two abreast and at the back when riding single file so as not to disrupt the ultrasonic measurements. Two other instrumentation boxes were fitted to the bicycles of riders who rode solo. These riders were instructed to pass other cyclists if necessary but to avoid grouping up with other riders.

All participants were given a map of the route and shown the end point. On their first ride they were driven to the start point of the route. All riders were instructed to ride in a safe manner and to follow the road rules and road signs. Any participant who felt unsafe or experienced an unwanted interaction with a motorist or member of the public was asked to return immediately to Roto-o-Rangi school and notify the Opus staff.

The rider groups set off at approximately 10 minute intervals, meaning all four rider groups were on the route at the same time. The riders rode the route through all three road treatments to a designated point, then chose to ride or were driven back to the start of the route. The route took an average of 30 minutes to ride. All participants had a break at 12.30pm for lunch and then continued to ride the route until 3.30pm.

Refreshments and water were available at the base throughout the day.

3.2 Data analysis

The quantitative data from the experimental study was analysed using the statistical analysis program ‘R’. The three key performances measured by the instrumented cycle in each road treatment were compared with the baseline and with each other in order to determine which road treatment had the greatest impact on behaviour.

Average speed data obtained from the Metrocounts was compared before and after the signage and sharrow treatments were installed. For the 2-1 condition, night and day time speeds during the treatment period (prior to its removable) were also compared.

4 Results

4.1 Bicycle instrumentation results

4.1.1 Instrumentation performance

In total, 136 recorded interactions were captured between instrumented bicycle riders and vehicle drivers on the day data collection took place. This is substantially lower than the expected rate of about 280 interactions/hour (based on average AADT with four instrumented cycles travelling on the route at any one time). The low number of interactions could be partially explained by some data loss due to lost connections on the device (from extended vibration of the units) and lower than expected vehicle numbers on the day. Of these 136 interactions, 85 (62.5%) were used for the analyses presented in this report. Almost one third of interactions were largely omitted due to data quality issues.

The instrumentation proved highly successful for identifying vehicles approaching riders from behind and starting video capture and recording vehicle and bicycle speeds. However, the ultrasonic device used to capture the lateral separation between riders and drivers (passing distance) had a number of false triggers that ended the recording prematurely (before the passing manoeuvre actually took place). The equipment could trigger on objects within 30m, so during instrumentation, piloting the distance was reduced to only trigger on objects within 5m to reduce false detections. However, going through the data, the device still had false detections, meaning sometimes a vehicle travelling in the opposite direction, or roadside trees and poles on narrow sections of the route were enough to stop the data capture. As the first real-world trial of the technology, beyond product testing over much shorter periods of time with fewer interactions, the overall performance of the instrumentation was satisfactory.

4.1.2 Descriptive statistics

Twenty-seven interactions between the instrumented bicycles and vehicles were recorded in the baseline sections of the route, 24 in the signage section and 34 in the sharrow section. The statistics and figures presented below combine data captured by riders travelling in solo and paired configurations unless stated. The mean, maximum and minimum values for vehicle approach speed, vehicle passing distance and bicycle speed were calculated for the signage and sharrow sections of the route and these were compared with the baseline.

Table 4.1 summarises the key performance measures for each treatment, and the following sections describe the results of the specific comparisons for each performance measure. It should be noted that, due to the low number of interactions in each category, the statistical power of these results is limited. Any insignificant findings may be the product of the small sample size rather than necessarily the lack of effectiveness of the treatments on trial.

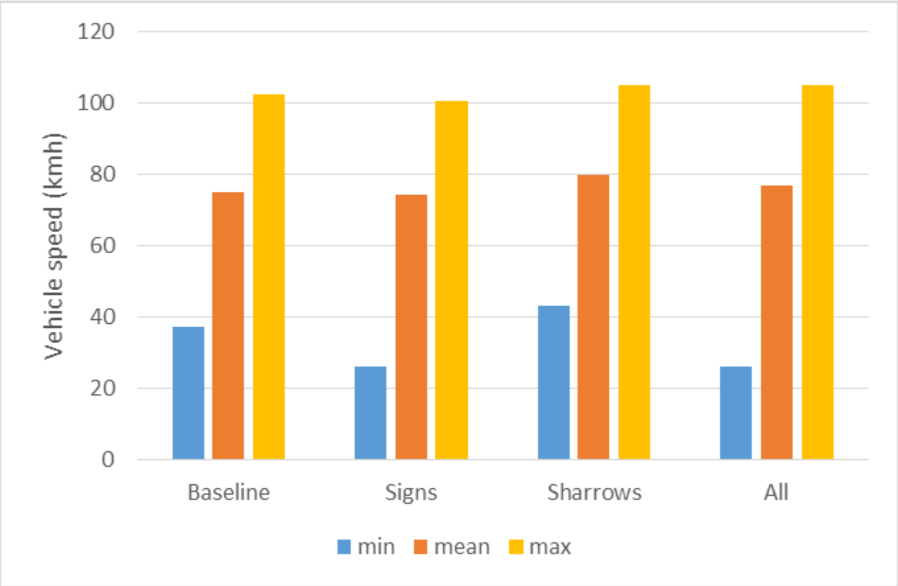
Table 4.1 Summary of performance measures by condition

Treatments	Interactions (N)	Bicycle speed (km/h)	Vehicle approach speed (km/h)	Passing distance (cm)
		mean (min – max)	mean (min – max)	mean (min – max)
Baseline	27	22.63 (13.15 – 30.78)	75.13 (37.39 – 102.53)	213 (110 – 344)
Signs	24	23.26 (15.04 – 31.15)	74.35 (26.11 – 100.51)	209 (115 – 340)
Sharrows	34	24.77 (14.39 – 34.67)	79.73 (43.38 – 105.19)	208 (111 – 370)
ALL	85	23.67 (13.15 – 34.67)	76.80 (26.11 – 105.19)	212 (110 – 370)

4.1.3 Approach speed

As a vehicle approached an instrumented bicycle, the radar detected and recorded the vehicle speed approximately four times per second. When a vehicle passed a cyclist, its average approach speed was calculated from the radar data and this became the approach speed value for that interaction. The mean approach speeds for baseline, signs and sharrows treatment were between 75km/h and 79km/h and did not differ significantly from each other (figure 4.1). The mean speeds for the three conditions were between 75km/h and 79km/h and the mean speeds for sign and sharrow treatments did not differ significantly when compared individually with the baseline ($F(2, 82) = 0.98$, $p = .38$, with a low effect size, r = 0.01) nor when both treatments were combined and compared with the baseline ($t(83) = 0.01$, $p = .99$). The overall average motorist approach speed across all conditions was 77km/h.

Figure 4.1 Comparison of vehicle approach speed for each treatment (left) and all conditions combined (right)



4.1.4 Passing distance

As a vehicle passed an instrumented bicycle, the ultrasonic sensor detected and recorded the vehicle passing distance. The mean passing distance, along with the minimum and maximum distances for baseline and the two treatment types are summarised in figure 4.2. The mean passing distances for the signs and sharrows conditions did not differ significantly when compared individually with the baseline ($F(2, 82) = 0.34$, $p = .71$), nor when combined and compared with the baseline ($t(83) = 0.12$, $p = .73$, with a low effect size, r = 0.01. The overall average passing distance across all conditions was 212cm.

Figure 4.2 Comparison of vehicle passing distance for each treatment (left) and all conditions combined (right)

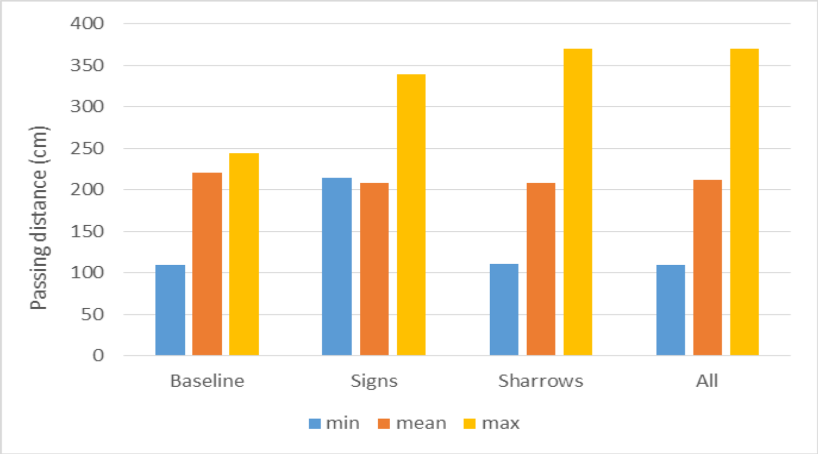


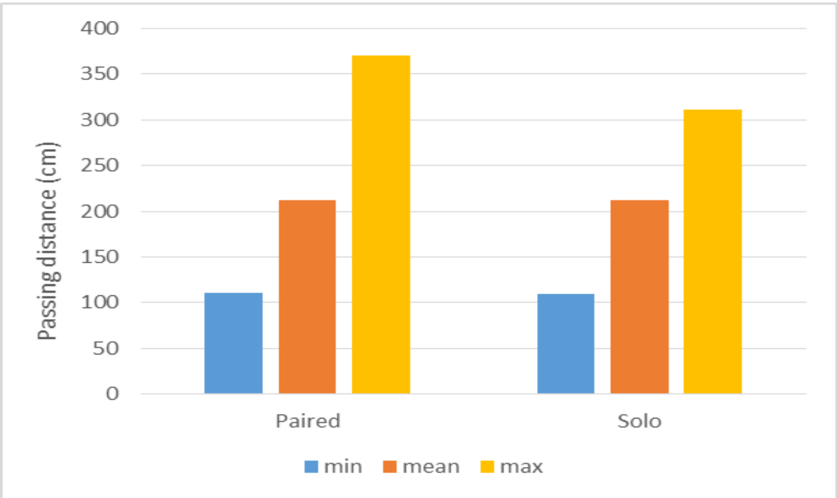
Table 4.2 shows the percentage of motorists who passed within 1.5m of the cyclists. This distance is recommended by the NZ Cycling Safety Panel for roads with speed limits of 60km/h and over. Under the sharrow condition there were more frequent close passing distances. Overall, the majority of motorists drove at a distance greater than 1.5m when passing; however, 18% passed within 1.5m of the cyclists.

Table 4.2 1.5m passing distance: percentage of drivers passing inside or outside of 1.5m

	<=1.5 m		>1.5 m	
	n	**%**	**n**	**%**
Baseline	4	15%	23	85%
Signs	3	13%	21	88%
Sharrows	8	24%	26	76%
All	15	18%	70	82%

The mean passing distance drivers gave to paired riders was compared with that given to solo riders across treatments. For both groups, the mean passing distance was 212cm, and hence not significantly different. This is illustrated in figure 4.3.

Figure 4.3 Comparison of passing distance between solo and paired riders



4.1.5 Bicycle speed

Bicycle speed was measured using GPS. The mean bicycle speeds for the three conditions did not differ significantly from each other when compared individually with the baseline ($F(2, 82) = 0.11$, $p = .90$), nor when combined and compared with the baseline ($t(83) = 0.12$, $p = .73$, with a low effect size, $r = 0.02$). This finding indicates that riders were travelling with some consistency between the conditions. The overall mean bicycle speed across all conditions was 23.67km/h.

On average there was about a 53km/h speed difference between cyclists and motorists. This was relatively consistent between conditions (with an average gap of 51–55km/h depending on condition, see table 4.1).

4.2 Metrocount results (fixed location motorist speeds)

Metrocount data from the following time periods was used to conduct pre and post treatment analysis of motorist speeds at specific locations:

- pre-treatment baseline: 16 July – 22 July
- advisory sign and sharrow treatments: 26 July – 7 August
- 2-1 treatment:
  - day time: 1.30 – 5.00pm, 24 July
  - night-time: 5.00pm – 8.00am 24 July – 25 July (based on the sun set and rise times for the time of year the Metrocounters were in place).

The statistical analysis showed that at the sharrow site, there was no significant difference between the baseline and treatment dates with drivers averaging 90km/h during both periods. At the advisory distance signage section of the route, motorists were slower in the treatment period ($M = 78.87$, $SE = 0.22$) than in the baseline period ($M = 80.59$, $SE = 0.34$). This difference was significant ($t(7445) = 4.29$, $p < 0.01$), which represented a small effect size $r = 0.05$. Motorist approach speeds (taken when overtaking cyclists) were also lower than the overall driver speeds collected at the fixed location of the two Metrocounters.

Drawing comparisons between the two speed measures (Metrocount fixed speeds and instrumented cycle approach speeds), there is evidence that motorists do slow down for cyclists when overtaking. Prior to the sharrow markings, the fixed location average motorist speed was 90km/h. With sharrow markings, the average motorist approach speed when overtaking cyclists was 80km/h (an 11% relative drop in speed). Similarly, prior to the speed sign change, the fixed location motorist speed was 79km/h compared with an average motorist approach speed of 74km/h (a 6% relative drop in speed) with the speed sign.

4.3 2-1 treatment – motor vehicle speeds

As already mentioned, the 2-1 treatments were removed after 24 hours, as it was observed that motorists did not reduce their speed, which is critical if the 2-1 is to be a safe space for cyclists. An analysis of day versus night speeds at the 2-1 site was conducted to support the observations of the project manager and the subsequent decision to remove the treatment. Southbound speeds for the identified time periods were examined, as this treatment was complete at the time. Overall, operational speeds were lower, at around 90km/h, than the speed limit zone of 100km/h (see table 4.1).

There was a significant difference ($t(479) = -11.68$, $p < 0.01$) between motorist speed during the day compared with at night for the period the 2-1 layout was in place, with drivers driving nearly 20km/h faster at night ($M = 80.56$, $SE = 1.08$) than during the day ($M = 62.15$, $SE = 1.14$,). This represented a medium sized effect $r = .47$.

During night conditions, motorists were driving slower when the 2-1 condition (combined with signage and speed zone condition) was in place (M = 80.55, SE = 1.08) compared with the baseline condition (M = 92.13, SE = .29). This was a significant difference, $t(2800) = -10.36$, $p < 0.01$, which represented a large-sized effect r = .51. This drop in speed of nearly 12km/h was lower than that during day conditions, where there was a drop in speed of nearly 28km/h.

During the daytime, the 2-1 was very effective at reducing speed, with 43.3% of motorists travelling at compliant speeds (60km/h or less), with an average vehicle speed of 62km/h. During day conditions, motorists were driving slower when the 2-1 condition was in place (M = 62.15, SE = 1.14) compared with the baseline (M = 89.6, SE = .26). This was a significant difference, $t(4390) = 23.39$, $p < 0.01$, which represented a medium sized effect r = .33.

Table 4.3 Average driver speeds, pre and during 2-1 treatment by time of day

	Day			Night		
	N	Average motorist speed (km/h)	85th percentile motorist speed (km/h)	N	Average motorist speed (km/h)	85th percentile motorist speed (km/h)
Pre 2-1 (100km/h speed limit)	4,177	89.6	103.3	2,218	92.1	104.4
2-1 (60km/h speed limit)	215	62.1	78.8	226	80.5	96.7

4.4 2-1 implementation site observations

During the implementation and operation of the 2-1 layout, an Opus engineer was on site to observe motorist behaviour and public safety during the day of installation and into the evening during darkness. The weather at the time was overcast but dry, there was no fog and visibility was good.

The key onsite observations were:

- During the daytime, motorists reduced their speed and observed the speed reduction (mean speed of 62km/h, and 85th percentile speed of 78km/h).
- During the evening (after 6pm), observed speeds were higher and this may have been because motorists assumed no road works were in place and they could travel safely at higher speeds (mean speed of 80km/h, and 85th percentile speed of 97km/h).
- Drivers were observed to move into the single lane formation without apparent confusion.
- Drivers adopted two common road positions when driving along the 2-1 section when there was no on-coming traffic:
  - centrally within the single traffic lane. Observed predominantly by commercial truck drivers and farm service (estimated to be 60% of traffic)
  - on the road straddling the white dashed edge line.
- The majority of drivers moved to the left to pass an oncoming vehicle, and were observed to further reduce their speed as identified by brake lights of passing vehicles.
- One potential safety risk was observed between oncoming vehicles (see section 3.1.2 for details).

Despite removal due to safety concerns, the anecdotal observations and findings gathered from this trial suggest there is the potential for motorist speed reduction, as exhibited by the slower daytime speeds. Similarly, most drivers were able to negotiate the 2-1 layout without incident. This indicates that future trials, if coupled with appropriate information and education, are worth investigating.

4.5 Summary

No significant differences were found between the signage or the sharrow treatment and baseline on any of the three key performance measures: approach speed, passing distance, or cyclist speed. Even when data from the sharrow and signage treatments was combined and compared with the baseline for these measures, no significant differences were found. Given the lack of significant differences between baseline and treatments, the data can be combined to provide overall baseline values for the three dependent variables for these kinds of roads in New Zealand.

The Metrocount data indicated that, while there was no change in average free-flowing vehicle speed as the result of the sharrows, there was a significant 2km/h speed reduction in the signage treatment area. The Metrocount data also showed that drivers were travelling, on average, 20km/h above the posted speed limit in the 2-1 area at night, supporting the decision to remove this treatment for the safety of cyclists and motorists. However, during the day, speed findings indicated the 2-1 design was successful at reducing speed (by almost 28km/h) when coupled with signage and a 60km/h speed zone change, indicating the potential of this design for future trials.

5 Project implementation: cost analysis

The project implementation costs are important as the cost of any improvement measure on any road must be balanced with risk exposure, traffic volume and number of cyclists (both existing and potential cyclists after improvements to cyclist safety). For lower-volume rural roads it may not be cost efficient to implement high cost safety improvements.

The costs to implement the trial measures are given in table 5.1. From the treatments implemented in this study, the rural sharrow markings were the lowest cost intervention, followed by the billboard signage option, then a road marking change. The overall cost to set up this trial was approximately $13,500, with a further $5,400 to reinstate the original conditions (remove 2-1 and signage, including traffic control).

Table 5.1 Costs to implement trial treatments

Item details	Cost breakdown ($NZ)	Total cost ($NZ)
2-1 road markings (includes traffic control, road marking blacked out not removed by water blasting)	$8 per metre	$6,400 (across 800m)
Road safety signs installed (includes traffic control, twin posts, and service check)	$850 per sign	$3,400 (4 new advisory signs)
Rural sharrow markings (includes traffic control)	$200 per marking	$1,600 (8 sharrows)
Supplementary warning plates (indicating new road layout)	$150 per plate	$900
Other items (including site management)		$1200
Setup sub- total		**$13,500**
Reinstatement costs (to return to original road conditions)		$5,400
Total		**$19,000**

Due to the relatively small (2km/h) speed change related to signage, the lower than anticipated cyclist–motorist interaction data from this site, and lack of data from other sites or regions, it is premature to undertake a cost–benefit analysis of billboard signage impact.

6 Discussion

While most cycling studies have focused on urban areas, this trial investigated the impact of cycle safety treatments on rural roads, where there is a gap in understanding how cyclist–motorist interactions could be improved. The total social cost to New Zealand of cyclist–motorist crashes on low-volume rural roads is about $16 million per year. This study considered the international best practice treatments and adapted them to the local New Zealand environment. The findings provide unique data on how much space is given to cyclists and how drivers react in terms of slowing down around cyclists in rural settings, arguably two key near miss indicators for cyclist safety (eg Aldred and Crosweller 2015) and certainly important to comfort and cycleway use (eg Sanders 2015). It also provides a method and instrumentation to capture this data in the future.

6.1 Baseline cyclist-motorist interaction data

6.1.1 Passing distance

The findings from the current study revealed that the baseline lateral distance or 'gap' was 212cm, with about four in every five motorists (82%) passing cyclists' safely outside the recommended 1.5m gap. A minimum of 1.5m is recommended to provide a comfortable gap for cyclists in speed zones of 60km/h or above (NZ Transport Agency 2014c). These distance results have two key implications.

First, that most drivers are able to overtake cyclists with the recommended 1.5m gap for higher-speed roads (even on narrow rural roads). This would vary based on road dimensions and context (including road hierarchy), and is relevant to many of our rural New Zealand roads. In a similar study, on a wider rural highway (a 9.2m wide road, with 1.2m shoulders and 3.4m traffic lane), about 9 in every 10 (89%) of motorists were outside this 1.5m gap when overtaking cyclists (Kay et al 2014).

Second, that on these types of road about one in five (18%) interactions are of concern due to insufficient space afforded to cyclists. This indicates there is room to reduce cyclist risk, and that this provides some benchmark data to test the success of future interventions. Further baseline data collection in different road conditions is warranted, as is an examination of the reasons behind variation in passing distance behaviour. Haworth and Schramm (2014) suggest there has been no systematic evaluation of the road safety benefits of minimum passing distances, so developing a better evidence base for recommended passing distances is also an area that could be explored further with better passing distance data.

6.1.2 Motorist approach speed

Baseline driver approach speed was around 77km/h, approximately 54km/h faster than the mean speed of the cyclists on the route. It should be noted that the speed of cyclists in this study may have been affected slightly by the instrumentation attached to their bicycles, (which weighed approximately 7kg). Typically speed monitoring only measures motorists, and mostly this is examined in low-speed urban environments, so the speed differential data is relatively unique here. Drawing comparisons between the fixed location speed measures and the overtaking approach speeds of cyclists within the same section of road indicates that motorists do slow down for cyclists (with relative drops in speed of 6% and 11% in the advisory signage and sharrow treatments).

6.2 Treatment findings

6.2.1 Advisory signage

The road treatment section with advisory signs recommending a safe passing distance between cyclists and motorists resulted in a 2km/h speed reduction by motorists. While this is a minor speed change (with a low effect size), this equates to a potential 4% reduction in crash risk (applying the Transport Agency's (2013) *Economic evaluation manual*), where every 1km/h speed reduction results in a 2% decrease in crash risk). In a recent US 'Share the Road' advisory signage study, Kay et al (2014) found a 4km/h reduction in motorist speed when these signs were present.

Vehicle approach speed and passing distance at the point motorists overtook cyclists (as captured by the instrumented bicycle data) indicated no significant effect of the advisory signage. However, the number of interactions (which were lower than anticipated) were not enough to draw a robust conclusion that this signage had no influence on motorist speed and space decisions when overtaking cyclists. Kay et al (2014) found a slight but non-significant shift away from cyclists in the presence of similar advisory signage. The US study did not specify a recommended distance, but simply had a cyclist symbol combined with 'Share the Road' text (Kay et al 2014). Overall, based on these findings it is suggested that advisory signage be used in conjunction with other treatments to enhance the safety of all road users (including cyclists), especially where lower speed (or smaller speed differentials) are likely to enhance safety.

During the site selection process it also became apparent that 'Share the Road' advisory signs vary across New Zealand regions, which is likely to be confusing for road users. This also has implications for cost, in terms of economies of scale around sign reproduction, but also resource related to the design and decision-making. Standardisation, including consistency with colour, shape and symbols is a key ergonomic principle behind effective sign comprehension and safe road user behaviour (eg Ben-Bassat and Shinar 2006). Standardised guidelines are needed to improve consistency, familiarity and road user understanding. In addition to the sign trialled in this study, international examples of these signs exist, for example, the 1.5m sign is a legal requirement in Queensland, Australia. It is an opportune time to develop design standards for 'Share the Road' signs in New Zealand.

6.2.2 Sharrows (shared lane arrows)

Sharrows were implemented at intersections and at road horizontal and vertical curves with poor line of sight to indicate that motorists should share the lane with cyclists. The results of the sharrow intervention were mixed. While the instrumented bicycle data did not reveal any difference in speed or passing distance of motorists (compared with the baseline), the data here was not sufficient to conclude definitively that sharrows have no influence with these performance measures. Similarly, when the fixed location speeds were examined, there was no difference with and without the sharrow. However, when the difference between the fixed location speeds (Metrocount data) and the approach speeds of motorists when overtaking (from the instrumented cycle data) were compared, the results not only indicated that motorists slowed down when approaching cyclists, but slowed down to a greater extent in the sharrow condition (as opposed to the signage condition). One interpretation of this result is that motorists are more attentive to riders when sharrows are present. Certainly under some urban New Zealand conditions the sharrow marking does reveal an average speed drop of about 6km/h (a relative drop of 14%, from 42km/h to 36km/h; Trotter et al 2015). Overall, the findings here are not definitive as to the efficacy of rural sharrows, especially as regards their use in combination with the 2-1 design.

6.2.3 2-1 treatment in New Zealand

In line with previous research, as well as collaboration with expert opinion, a 2-1 treatment was selected, as it has been shown to have potential safety benefits for cyclists (eg Jaarsma et al 2011; Schermers and van Vliet 2001; SWOV 2013). The 2-1 design trialled a combination treatment, which included advisory cyclist overtaking signage, new road layout warning signage, a speed zone of 60km/h, and finally the 2-1 marking layout (with two cycle shoulders and a shared central motorist lane). Based on the fixed location speeds examined in the 2-1 treatment, the design was successful during daytime at reducing average motorist speeds from about 90km/h down to 62km/h. Similarly, in the short observation period of the 2-1, the majority of drivers responded appropriately to the new layout (with the exception of one observed potential safety incident).

The 2-1 design trial was discontinued within 24 hours of implementation due to safety concerns relating to motorist behaviour (prior to trialling it with the instrumented cycles). The key safety concerns related to high night driving speeds, an observed near miss incident, and some negative motorist feedback (see section 3.1.2 for more detail). Motorists' high speeds at night may have simply related to a lower expectation of cyclists being on the road at night. Similarly, the use of vehicle headlights (or bicycle lights) providing early awareness of other road users at limited sight line locations (intersections or horizontal or vertical curves) at night may have had an influence. Also, speeds to tend to increase during night periods where the perceived likelihood of speed enforcement is lower. Regardless of these factors the night motorist speeds are an issue that should be considered in any future 2-1 trial. If design solutions are not enough, speed enforcement options could be examined.

The public complaints from motorists and the near miss incident appeared to relate primarily to discomfort from not knowing the appropriate behaviour. In particular, there was a lack of confidence or confusion around the correct motorist yielding behaviour when cyclists were encountered at the same time as oncoming vehicles. However, this could have been countered through improved education, or on-road notifications of expected motorist behaviour (eg more explicit signage).

These findings highlight the importance of educating drivers in how to use new road layouts, which is supported by the findings of Erke and Sorensen (2008), who partially attributed failure of 2-1 layouts to lack of usage education. In terms of usage education, the core reasons offered for why motorists did not shift their position on the road was related to motorists believing the edge strip was a cycle lane they could not enter, and motorists failing to recognise that they needed to give way to cyclists (Erke and Sorensen 2008). In the New Zealand trial, attempts were made to attend to these issues through the design process (see section 2.6.1 for more detail on design considerations). Often there is a necessary balance between deception and revelation that must be maintained within a research project in order to test the intuitiveness of new treatments. However, in countries such as New Zealand (where cycle-supportive road layouts are uncommon and are not part of the road code or licensing process), explicit information and education must be a focus, both in the interest of safety and community buy-in.

Despite removal due to safety concerns, the anecdotal observations and findings gathered from this trial suggest there is the potential for motorist speed reduction, as was exhibited by the slower daytime speeds. Similarly, most drivers were able to negotiate the 2-1 layout without incident. This indicates that future trials, if coupled with appropriate information and education, are worth investigating.

6.3 Lessons for 2-1 designs

6.3.1 Explicit behaviour-based signage

While signage has limitations, a benefit of a sign-based approach is that all motorists driving through the site are exposed to this information (as opposed to other education initiatives that may provide more detail, but are likely to have lower penetration amongst road users). The benefit of behaviour-based signage and iconography can be used to explicitly identify correct behaviour. This is already done in the US for their adaptation of the 2-1 design (see figure 2.17; Hanover Department of Public Works 2013; City of Banks 2015). There are good ergonomic and cognitive principles underlying this approach. For example, the use of icons is less cognitively demanding on drivers, as icons are faster to process than text (particularly if familiar, eg Ben-Bassat and Shinar 2006). Successful iconography does require a good balance between ensuring the message is sufficiently complex to allow understanding without being too complex (to avoid confusion or greater processing time).

Building on the example signage, dynamic iconographies could also be used. Dynamic icons better depict movement in a static image, and there is evidence these images improve comprehension, attention and safe behaviour (Cain et al 2015). For example, the motorist direction could be shown by shifting the direction of the motor vehicle (currently the vehicles depicted in figure 2.17 are moving straight towards each other). Similarly, the cyclist movements should show the cyclist moving in parallel to the motorists (as opposed to perpendicular, which could take longer to process), and any give way signage should ensure clarity around who should take priority. Ideally symbols should also be coupled with complementary text, which is especially useful for novel signage where there is less familiarity (Shinar and Vogelzang 2013).

6.3.2 Repeat signage

Reminder signage during the treatment was only used for the 60km/h speed zone sign (this speed sign repetition has been shown to improve speed limit compliance, eg Jongen et al 2011). Future trials may also consider the use of additional signage every time the 2-1 treatment begins (eg after side roads or curves where there is a short gap). Following the same logic as with speed signage, this repetition is likely to improve behaviour.

6.3.3 Site selection

The operational speeds of vehicles were about 10km/h below the posted speed limit at this trial location. However, locations with either lower operational speeds or sites with lower existing posted speed limits (eg 60km/h) would be favourable. The community should also be considered in the selection process to assist with local support and add local knowledge (see also section 6.4.1).

6.3.4 Edge lines

Edge line markings were not used in this trial (in combination with the 2-1 road marking), even though the New Zealand topography had more winding roads than some of the countries for which the design was developed (eg the Netherlands). The absence of edge lines could make driving on winding roads particularly hazardous at night, as it might reduce a motorist’s sight distance, or even a cyclist’s ability to detect the road edge in poor visibility conditions. However, there is some evidence that edge lines may not be required in 2-1 designs. Arguably, the high night-time speeds (relative to day speeds) indicate that drivers did not have any trouble negotiating this particular rural New Zealand road with only the dashed shoulder line markings provided by the 2-1 layout.

6.4 Lessons around trialling new road environments

The trialling of the 2-1 treatment has provided invaluable information regarding how new road layouts are likely to be received and reacted to in the New Zealand context.

6.4.1 Community consultation, education and awareness

Lessons from the 2-1 trial indicate that involving the community in discussions around the implementation of the research from an early stage of the project (eg through more extensive engagement with council and community groups) can enhance the level of community engagement and ultimately the acceptance of new treatments. This also aligns with findings around community engagement with Quiet Lanes in the UK, where the first step was to engage and involve the local community throughout the process to encourage buy-in to behaviour change (DfT 2004). Another option to improve community engagement could be to involve local community members in the site selection choice, gathering local knowledge related to where they believe the 2-1 treatment would have the best outcome and establishing their rationale for this (even if this choice was supported via an expert-informed list of options).

The current study has also highlighted the importance of both education and communication/awareness campaigns in the introduction of new road environments. However, the findings from the current trial emphasise that adequate and consistent behaviour change necessitates both implicit (ie a new road layout) and explicit (ie education/awareness campaigns) components. Thus, one important lesson drawn from the current research is that it is a joint responsibility of both the Transport Agency (as the funder) and the delivering organisation (in this case Opus) to ensure sufficient explanation of any new layouts or other on-road treatments is provided so that motorists and the community as a whole understand the importance of the key performance measures (in this case, of giving cyclists sufficient space and slowing down in areas where cyclists are present) and hence, the necessity of new road treatments.

Wider consultation and education is perhaps most relevant in relation to trials involving road users who may be less prevalent or well represented, such as cyclists on rural roads. For example, in regional areas in Australia, there was evidence from perception studies that when asked about ‘other drivers’, it was perceived that about two in three ‘other drivers’ did not consider cyclists to be legitimate road users (Johnson and Le 2012). This is similar to some of the public feedback from the 2-1 trial. This indicates there are underlying social norms around the dominant road user that should be considered when looking at interventions that attempt to address road user priority.

6.4.2 Balancing innovative design with practical implementation

Aside from the efficacy of road treatments, the present investigation has provided us with valuable lessons concerning the balancing of project scope and cost efficiency. Indeed, a key element to this study was to ensure the selected treatments were cost effective for a low-volume rural road network. A benefit to this approach was that any findings would provide the evidence for practical and implementable solutions. However, a lesson here is that in the trial decision making, a balanced approach between practicality and innovation can be difficult. For example, a decision process where there are practical implementation, legislative and cost concerns may narrow the stretch and innovation too early in the research process. Where resources allow, a two-phased approach to selecting trial conditions could be used to overcome this, with 1) an ideal situation with a full suite of complementary treatments, and 2) a more practical, moderate application of the same treatment. A key benefit of the full trial is that it allows testing the highest level of treatment benefit, and a key benefit of the practical trial is that it is easier to implement.

6.4.3 Additive versus solitary treatments

One plausible interpretation of limited treatment effects for the advisory signage or sharrows may be that, while these treatments alone may not be sufficient, they could still be effective as part of a combination treatment. Although the treatments were intentionally combined (sequentially adding, rather than being done in isolation) to assist in overcoming this issue, a more robust treatment may be required. This has been the case in other New Zealand behavioural studies, where multiple key visual features have to change in an environment before driver behaviour is influenced in terms of who has priority over the shared road user space (eg Thomas and Tate 2004). The solution may be the use of signage, sharrows and other measures in conjunction with each other. This concurs with lessons learned in European jurisdictions (eg Erke and Sorensen 2008) where 2-1 implemented in isolation has failed to have the desired effect on road safety outcomes, but 2-1 implemented in conjunction with a suite of other measures, such as threshold treatments (eg markings, speed bumps, bollards) and mid-block treatments has been more effective (Jaarsma et al 2011; Davidse et al 2004; Van der Kooi and Heidstra 1999).

7 Recommendations

Based on the findings of this project, Opus Research recommends that the following be considered:

1. **Further 2-1 trials in the New Zealand context:** Future trials are recommended to further inform the 2-1 design applicability in the New Zealand context. These design trials need to be conducted in conjunction with robust threshold and midblock treatments, including more active speed management measures (particularly at night). Complementary behaviour-based signage must be used to ensure all road users in the treatment location are exposed to explicit information demonstrating correct user behaviour. Similar, low-volume rural road designs with limited space (such as roads with no centre lines) could also be used to draw comparisons with user behaviour on existing New Zealand roads.
2. **Community consultation, communications and engagement strategy:** While the 2-1 design may be intuitive to most motorists and cyclists, any future trials of the 2-1 design (or other new or innovative designs) must be accompanied by a robust communications and engagement strategy, including education about new road layouts use and potential benefits. This communications strategy should be the joint responsibility of the appropriate road controlling authorities and the research and evaluation team, and should obtain a high level of community buy-in before trials proceed to implementation (see Discussion for specific suggestions).
3. **Advisory distance signs:** Use advisory distance signage as part of a suite of measures to improve the safety of cyclists on rural roads. These signs have been shown to lead to a significant reduction in vehicle speed (a speed reduction that has the potential to benefit the safety of all road users).
4. **Standardised advisory signs:** The Transport Agency could consider the development of a standardised advisory sign to encourage desirable overtaking behaviour when passing cyclists, and guidelines for its use to ensure consistency across the national network. The sign used in this project is similar to that being trialled for high-risk motorcycling routes (so is consistent), and has been shown to lead to speed reductions, so could serve as a starting point for this development.
5. **Baseline cyclist–driver data:** A robust baseline of how drivers and riders interact in different settings and road hierarchies would better inform and monitor safety intervention outcomes.

8 References

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