
# REDUCING 'FAILED TO DETECT' CRASHES AT RURAL CROSSROADS

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# Executive Summary

A project conducted by Mackie Research and funded by the AA Research Foundation


## Project Outline

In many rural crossroads crashes, drivers may be failing to detect the intersection in time to safely stop. However, a better understanding is needed about the frequency and nature of these types of crashes, and whether additional controls might provide safety benefits.

This research project aimed to fill this knowledge gap by gathering data on how often ‘failure to detect’ crashes occur, analysing the likely causes, and then testing possibilities for mitigations.

## Methods

A crash data analysis of 305 rural crossroads crashes, with a particular focus on 42 ‘failed to detect’ crashes, built insight into crash frequency and causal factors.

Following this, a trial of practical and cost-effective ‘failure to detect’ mitigations, predominantly using existing Traffic Control Devices (TCDs), was undertaken with 60 participants using virtual simulation technology.


Baseline

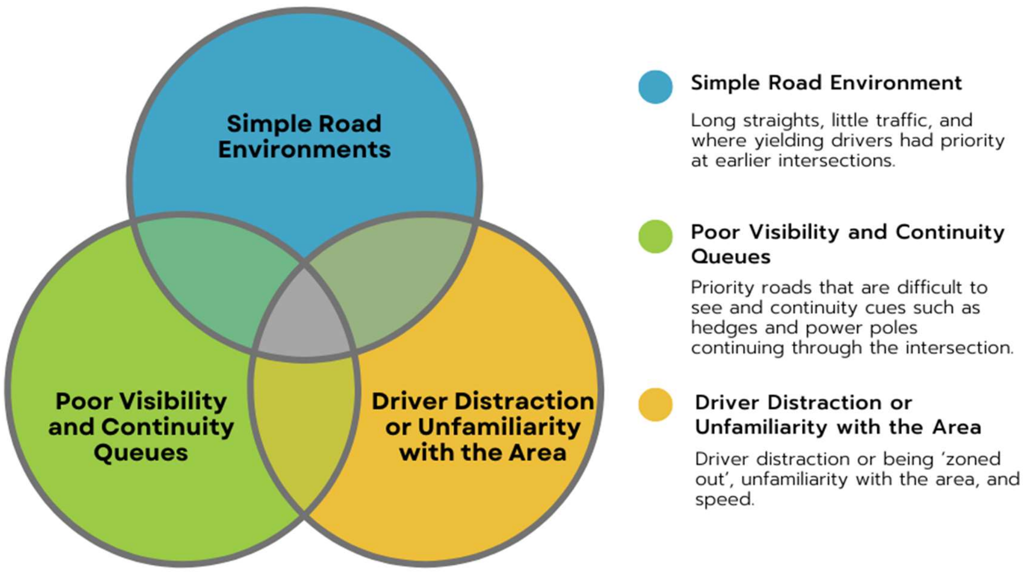

Mitigation 1


Mitigation 2

## Findings - Crash Factors

Rural crossroads have a unique set of crash characteristics. **Nearly one third of rural cross-roads crashes appear to occur because the yielding driver does not detect the crossroad ahead and fails to stop or give way.** These types of crashes are much more common at crossroads than other intersection types.

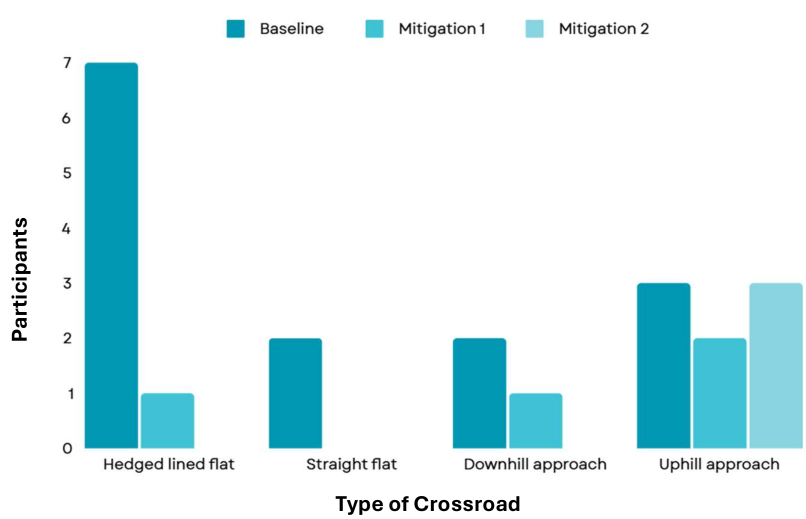
Through an analysis of crash reports, we identified environmental, road geometry, and driver factors associated with 'failed to detect' crashes. Conditions involve:




## Findings - Crash Mitigation

The addition of commonly available TCDs saw a dramatic improvement in the detection of most crossroads. Although, interestingly, the addition of a white backing board on Stop warning signs led to sign recognition uncertainty for some participants.

**Number of participants who saw the intersection dangerously late (within 100m)**

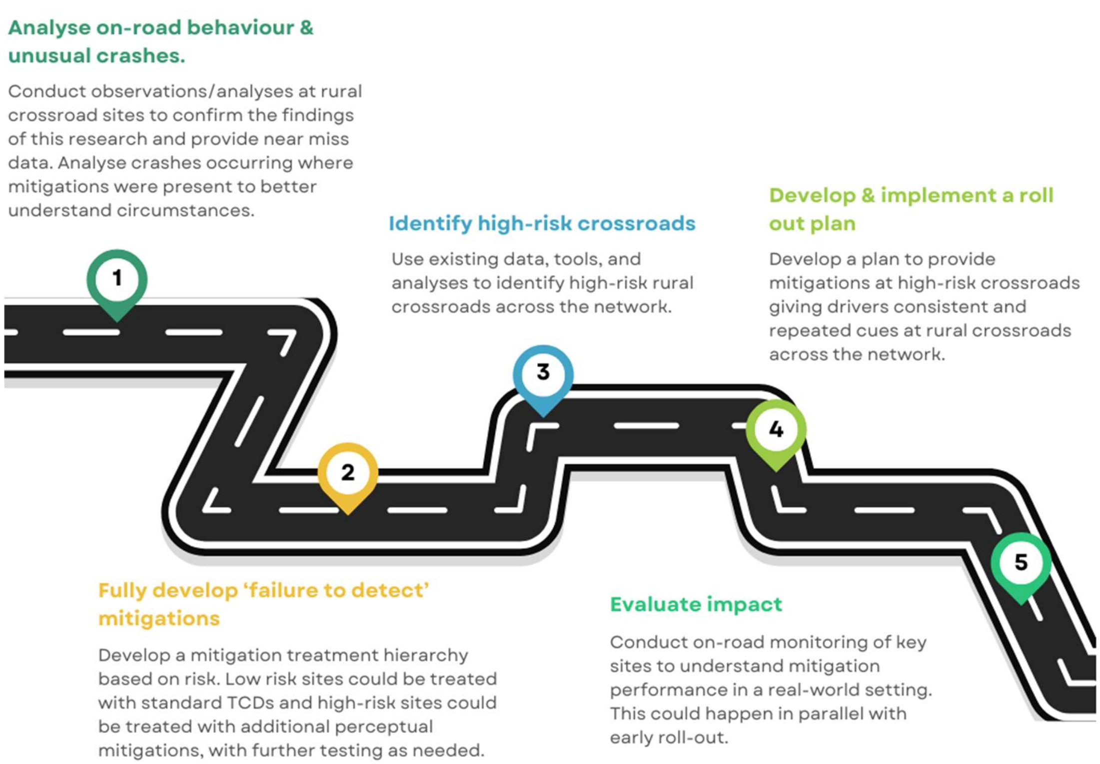


## Conclusions and Recommendations

Rural crossroads have a unique crash profile, which appears to be related to the surrounding environment and road geometry as much as driver factors. Failing to detect the crossroad is a common crash cause at rural crossroads compared to other intersection types.

The current minimum standard mitigations for rural crossroads (a single Stop or Give Way at the intersection) may not be sufficient in some contexts. However, this trial showed that existing TCDs can be used to improve crossroad detection.

This study, in combination with other research, should provide road controlling authorities with the confidence to develop and roll out a nationwide low-cost treatment approach to mitigate 'failure to detect' crashes. Specifically, the following steps are recommended:



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# 1. INTRODUCTION

In New Zealand, crashes at all types of rural intersections are relatively common, despite the low traffic volumes on most rural roads. Waka Kotahi statistics show that 17% of deaths and serious injuries on rural roads occur at intersections (NZTA, 2013). The frequency and seriousness of these crashes emphasises the importance of safety interventions. However, many rural intersections are controlled with only a single Stop or Give Way sign.

In recent years, several high-profile crashes have drawn attention to issues at one particular type of intersection, rural crossroads. Road safety experts have noted that a major causal factor in these crashes appeared to be the yielding driver failing to detect the crossroad. If ‘failure to detect’ errors are widespread, this potentially points to a deficiency in either the standard controls for managing traffic at these sites, or the maintenance of these controls. However, because the frequency and characteristics of ‘failure to detect’ crashes at crossroads are not currently well understood, road safety engineers cannot make informed decisions about where further controls might provide safety benefits.

Additional controls (e.g. Figure 1 below) are sometimes used at rural crossroads. This suggests that road safety engineers are aware of the issue of motorists not detecting intersections and the need for additional interventions. Further evidence of the extent and nature of ‘failed to detect rural intersection crashes, along with evidence of the effectiveness of low-lost treatments, would give confidence to a nationwide treatment strategy that would yield tangible safety benefits.


*Figure 1: Oversize Stop signs at Mitcham Hepburns crossroad, Canterbury NZ.*

Therefore, this research project aims to build a better understanding of the frequency of ‘failure to detect’ crashes on New Zealand roads, the likely error mechanisms, and possibilities for effective, cost-efficient, mitigations that could be broadly rolled out across New Zealand. The focus of the project is less about identifying innovative solutions, and more about giving confidence to any large-scale roll out.

Specifically, the research has two goals:

1. To better understand the Safe System conditions and human factors considerations associated with ‘failure to detect’ crashes at rural crossroads.
2. To identify and test the effectiveness of mitigation options to reduce ‘failure to detect’ errors at rural crossroads in New Zealand.

The project builds on an existing body of work focused on improving safety at rural intersections (summarised briefly in the following section). Most particularly, it is influenced by work undertaken by the United States Federal Highway Administration (FWHA) who, over many years, have developed a programme to broadly implement packages of low-cost interventions at rural intersections. The results from several States have shown some notable success (FHWA, 2018).

The project also builds on New Zealand-based work undertaken by (Harris & Blackmore, 2022) which focused on identifying high-risk rural crossroads. This project adds value by 'drilling down' into 'failure to detect' crashes and providing a more detailed understanding of crash frequency, causal factors, and the likely effectiveness of potential mitigations.

*Figure 2: Typical features of an approach to a rural crossroad in New Zealand*

# 2. CURRENT KNOWLEDGE

As rural intersection crashes are a common problem in many countries, there is a significant body of research on crash characteristics and possible mitigations. Within this section, a brief outline of some of the most pertinent findings are provided, taking a human factors perspective.

## 2.1. Crossroads navigation

In general, driving is a complex interaction between the perceptual, cognitive, and motor systems of the driver. Effective mitigation of rural crossroads crashes requires an understanding of the specifics of the crossroads navigation task and potential error points.

The following high-level task analysis completed by the HumanFIRST research team at the University of Minnesota describes intersection negotiation from a perceptual and cognitive point of view (Creaser et al., 2007). It shows that crossroads navigation requires accurate visual perception (search and detection), speed and distance perception, the ability to manage attention (e.g., traffic monitoring) and safe response selection. There are many points in the task where a driver error may result in a crash.

*Table 1: Rural crossroads task analysis. Adapted from HumanFirst*

| Task Goal | Task | Sub-Task |
|---|---|---|
| Approach intersection | Detect intersection | Detect intersection features such as signs, signals, pavement markings, and curb edges. |
| | Decelerate | Apply brake. |
| | Enter correct lane (if needed) | Determine if already in desired lane. If not, scan mirrors and/or shoulder for conflicting vehicle. If vehicle present, detect and estimate gap, accept/reject gap, and change lane. |
| | Signal (if required) | Apply correct signal well in advance of intersection. |
| Assess safety of entering intersection | Detect traffic-control device | Detect signs or signals (if present). |
| | Interpret traffic-control device | Understand sign or signal. Be knowledgeable of right-of-way rules. React appropriately and stop or slow down as needed. |
| | Monitor lead vehicle (if present) | Observe path of lead vehicle and anticipate stops. Estimate speed, distance, and gap. Adjust headway as needed. |
| | Detect traffic and pedestrians | Detect intersecting traffic and/or pedestrians. Yield as required. |
| | Detect, evaluate, and monitor gaps in traffic | Detect gap. Estimate speed, distance, and arrival time. Perceive gap size. Evaluate whether gap is acceptable. Monitor changes in gap size. |
| Traverse intersection | Accept gap and complete manoeuvre | Determine when to initiate manoeuvre. Check pathway for obstructions. Yield and adjust velocity as required. If turning, turn steering wheel, accelerate, and adjust speed to traffic. If straight, accelerate. |
| | Monitor until intersection is cleared | Monitor traffic, pedestrians, or lights. Anticipate light changes (if relevant) and sudden stops, accelerations, or violations by other traffic. Yield or slow down as required. |

## 2.2. Crossroads navigation errors

Given the cognitive complexity of intersection navigation, it is not difficult to see why crashes occur at these sites. Typical rural environmental factors such as high-speed roads, limited road marking and signage, gravel, and poor sight lines to intersections, further increase the risk of high severity crashes (NZTA, 2013).

In terms of understanding what errors commonly contribute to intersection crashes in general, several researchers suggest that a useful first question to consider is 'did the yielding driver stop?'. Asking this question leads to two broad categories of potential errors:

1. failure to detect the intersection or slow adequately before entering it.
2. failure to detect oncoming traffic, anticipate its behaviour, or estimate its velocity/ distance.

Mitigating these two categories of error requires quite different types of intervention. Across all types of rural intersection, crash analyses find that both error types are present. There wasn't sufficient information in the literature reviewed to confidently draw conclusions about whether the frequency of each error type differed based on the type of intersection under consideration.

At rural crossroads in particular, crash analyses have found characteristic 'failure to detect' factors of inattention/distraction (failure to see the intersection) or vehicle speed (meaning the driver did not react in time) (Choi, 2010; Hallmark et al., 2018; Thompson et al., 2006). This indicates that these types of errors are present at rural crossroads. However, as with rural intersections generally, the frequency of 'failure to detect' errors wasn't discussed in the literature reviewed.

In New Zealand, there are media articles describing high-profile crashes at rural crossroads where drivers appeared to fail to detect the crossroad[1]. The data provided in the High-Risk Rural Roads Guide on crash movements at rural intersections also suggests 'failure to detect' crashes are occurring (NZTA, 2013). However, the information is not detailed enough to draw any conclusions about the overall contribution to crashes this error type makes at New Zealand's rural crossroads.

An expert witness statement for one 'failed to detect' crossroads crash, provided to this research team does give some insights into possible causal factors for 'failure to detect' crashes. The following factors, present at the time of the crash, were considered by the crash investigator to have made the crossroad more difficult for a yielding driver to detect:

- long straight alignments
- low volumes of traffic
- poor visibility of the other road
- poor visibility of other vehicles
- poor visibility of the signs and markings
- trees or poles that draw the eye through the intersection

[1] For example: https://www.odt.co.nz/news/national/moments-carelessness-four-dead-crash-near-ashburton.

What is clear from a review of international and national research/information about rural crossroads crashes is that more needs to be understood about the frequency of 'failure to detect' crashes and the factors contributing to this crash type before firm recommendations about interventions can be made. The first phase of this project was designed to provide more detailed analysis of this crash type enabling relevant mitigations to be created and trialled.

## 2.3. Crash mitigations

The gap in our knowledge about causal factors for 'failed to detect' rural crossroad crashes notwithstanding, there is an existing body of useful literature covering interventions to reduce rural intersection crashes in general.

*Safety interventions*

Interventions to enhance the conspicuity of rural crossroads are well known by most road safety engineers, and a review cataloguing options for safety interventions has previously been undertaken by Mackie Research (Luther et al., 2021).This review found that, although the quality and sufficiency of evidence for effectiveness was mixed, a wide range of low-cost intervention options are available. Based on the effectiveness and cost-benefit information available at the time, and taking into consideration NZ conditions, the team recommended that the following low-cost types of interventions may be effective in improving rural crossroad safety:

1. Double-width limit lines
2. Painted 'Stop ahead' markings
3. Transverse rumble strips
4. Gated (double) Stop signs
5. Highly retroreflective Stop signs
6. Maximum sized Stop signs.

In recent years, a study of a specific intervention, Stop Ahead signs (also called Stop Ahead Advanced Warning Signs) was also undertaken in New Zealand. The signs had two LED lights on either side of the stop ahead 200m advance warning sign which was integrated into a black backing board and was larger than a standard warning ahead sign. The lights were solar powered and activated by radar installed on the sign which detected approaching vehicles approximately 150m from the sign. The signs flashed alternately to warn drivers. The estimated cost of the supply of signs, posts, ground sockets and the installation of the sign was approximately $6000 per sign. The interventions were installed at four rural intersections in the Selwyn District. Unfortunately, insufficient data was collected to draw definitive conclusions about the effectiveness of the signs.

*Systemic approach to implementing interventions*

While work assessing individual safety interventions is useful, a major challenge for road controlling authorities is developing a strategy for rolling out interventions across large geographic areas.

A successful example of a systemic approach is provided by the Federal Highway Administration (FHWS) who, over a period of at least 10 years, has supported large scale roll outs of rural intersection safety interventions across a range of American states with notable success (FHWA, 2017). The premise behind the FHWA approach is that while it is not possible to predict exactly where crashes will occur, roadway characteristics associated with severe crash types can be used to identify risky locations at which low-cost interventions can be proactively rolled out, before a serious or fatal crash occurs.

The FHWAs approach has three main components (FHWA, 2020):

1. Analyse system-wide road characteristic and crash data to identify a problem.
2. Look for similar risk factors present in severe crashes.
3. Deploy low-cost, proven, countermeasures that address the risks.

Given this proven approach from the United States, it appears that New Zealand also needs a country-wide approach to rural crossroads safety, with a standard suite of proven low-cost treatments that can be used widely. The work undertaken by Harris & Blackmore (2022) provides NZ road controlling authorities with a head start in this approach. This project will provide a greater depth of knowledge on rural crossroads crashes and appropriate mitigations to allow such a strategy to progress.


*Figure 3: Rural crossroad in New Zealand with oversize Stop signs.*

# 3. RESEARCH APPROACH

This project was undertaken in two phases:

1. An analysis of crash data for rural crossroad crashes (2018-2022).
2. A virtual simulation trial of ‘failure to detect’ mitigations (packages of safety interventions).

## 3.1. Phase 1: Crashes Data Analysis

The purpose of the crash data analysis was to build insights into the frequency of ‘failed to detect’ crashes at rural crossroads, and the system factors associated with them.


The source data for the analysis was traffic crash reports (TCRs) from NZTA Waka Kotahi’s Crash Analysis System (CAS). This information was supplemented, where possible, with Serious Crash Unit (SCU) or Coroners reports and google maps images of the site. The steps involved in the analysis are listed below.

**Step 1:** CAS was queried to identify rural intersection crashes occurring between 2018-2022. The query was kept deliberately broad so that the starting dataset included fatal or serious crashes at *all* types of intersections on rural roads with an open speed limit. This enabled a comparison of the frequency of ‘failure to detect’ crashes at crossroads with other intersection types.

The query included all rural intersection crash cause codes that appeared to be related to lack of attention, misjudgement of speed, failing to stop, or failing to notice a sign. The initial, cleaned, dataset included 305 crashes.

While the dataset was not an exhaustive list of all fatal and serious rural intersection crashes, the team felt it was sufficient for analyses to be undertaken.

**Step 2:** All 305 crashes (all intersection types) were reviewed and, where there was sufficient information, a causal code was attached indicating whether the main crash cause was (a) yielding driver failure to detect the intersection, (b) yielding driver failure to give way to oncoming traffic, or (c) other (e.g., a vehicle on the priority road turning right into oncoming traffic). Information used to assign causal codes was typically attending officer observations, comments by witnesses or passengers, and information provided by the drivers involved. It is, by its nature, relatively subjective. Therefore, a sample of coding was reviewed by another team member as a quality control measure.

**Step 3:** In the dataset of 305 crashes, 144 occurred at rural crossroads. Forty-two of these crossroad crashes were identified as *'failure to detect'*. These 42 crashes were the focus of more a detailed analysis and were coded against a Safe System/Human Factors checklist. The checklist covered crash characteristics, road and roadside factors, environmental factors, road user factors, and vehicle factors.

## 3.2. Phase 2: Mitigation trial

The purpose of the mitigation trial was to co-design and test several cost-effective mitigations,[2] for 'failure to detect' crashes at New Zealand rural crossroads. The goal was to better understand what types of signage and markings are visible and attention-grabbing for yielding drivers on the approach to a crossroad, and hence are most likely to improve intersection compliance.

To achieve this goal, trial participants viewed video of several New Zealand rural crossroads with different mitigations inserted using video augmentation technology. The team then measured when the crossroad was detected and what participants were observing as they approached the crossroad. Participants were also surveyed to gather their views on the different interventions that formed part of the mitigations (e.g. transverse lines). Details of each aspect of the trial are provided below.

### *Trial Design*

The structure of the trial was co-designed with road safety experts. A 4X3 design was chosen - four roads and three treatment conditions (including standard treatment). This option provided the opportunity of testing mitigations on a range of road geometries (as requested by industry experts). In addition, a wide range of interventions (as part of each mitigation set) were able to be tested. This approach provided as much testing coverage as possible within project constraints.

It was decided that the trial would focus on daylight hours driving as most of the crashes identified in Phase 1 occurred during the day and under good visibility conditions.

### *Crossroad selection and filming*

The project team worked with industry experts to define selection criteria for crossroads to be included in the trial. The following criteria were chosen as geographical characteristics often present in the crashes examined in Phase 1:

- The yielding approach is straight.
- The priority road is difficult to see.
- The yielding approach is flat (although some crashes have occurred on slight downhills or at the top of a rise).
- There is limited skew on the yielding road after the crossroad.
- There are roadside continuity cues.
- Drivers had priority at earlier intersections.
- The surrounding road network is relatively simple (long straights, minor roads).

[2] Each including multiple individual safety interventions (e.g. transverse lines, oversize signs, gated signs).

Consideration was also given to including both minor yielding roads (e.g., no centre line, narrower etc.) and more developed yielding roads (e.g., centre line, wider etc.).

Ultimately, 12 candidate crossroads in Auckland and Christchurch were selected to be filmed and potentially included in the trial.

Crossroads were filmed using a GoPro video camera affixed to the vehicle screen at the drivers' eye level and as close to the driver horizontally as was safe (see Figure 4). This location provided a view as close to that experienced by the driver as possible.

Having tested a range of options for camera settings, the following settings were selected as providing the most realistic video of the rural scenes being filmed:

- Linear, horizon lock
- Resolution 4K
- Frame Rate 60 frames per second

Filming took place during daylight hours and in good weather. At each crossroad site, a route of approximately 5 minutes was filmed, with at least 3 minutes of driving prior to arriving at the crossroad. The filming vehicle travelled at a target speed of approximately 80km/h. This was based on testing prior to filming where the team found that this speed provided the most 'realistic' impression of general rural travel speeds when presented on screen.

Once filming was complete, the team reviewed all footage, and 4 sites (shown on the following pages) were selected for inclusion in the trial. Two sites fully met the selection criteria listed previously. An additional two sites met all of the criteria and were deliberately chosen to provide a comparison to the flat approach.

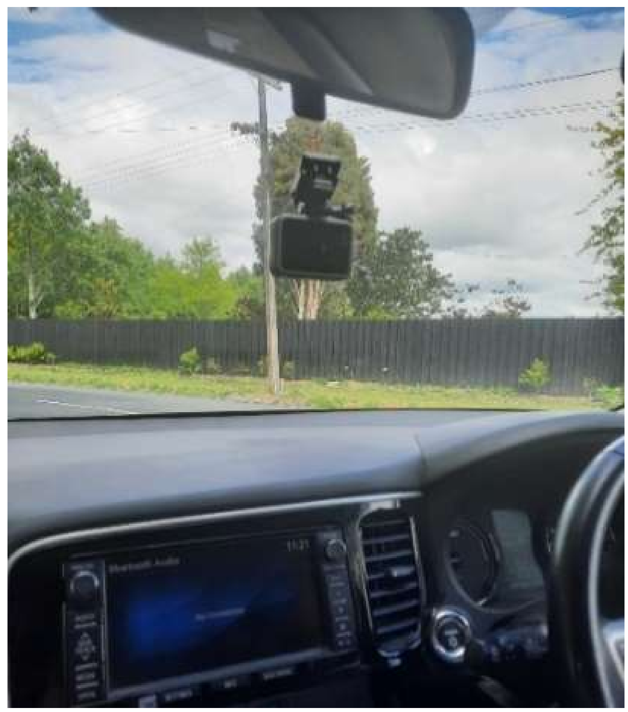


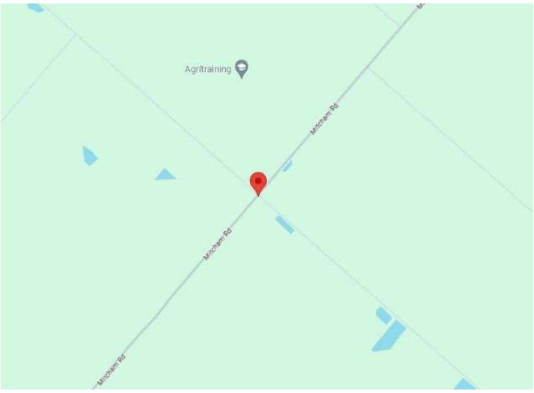
*Figure 4: Video camera positioning.*

The four sites are displayed below, alongside accompanying images taken during the filming process and a Google Maps screenshot. Each site has been given a **descriptive name** and will be referred to using this throughout the rest of this document.

Ashburton District: **Hedge Lined flat Crossroad**

Intersection of Dromore Methven Road (yielding) and Mitcham Road.

- Flat geography
- Priority road difficult to see
- Visual continuity (long hedge)
- Long straight prior to crossroad

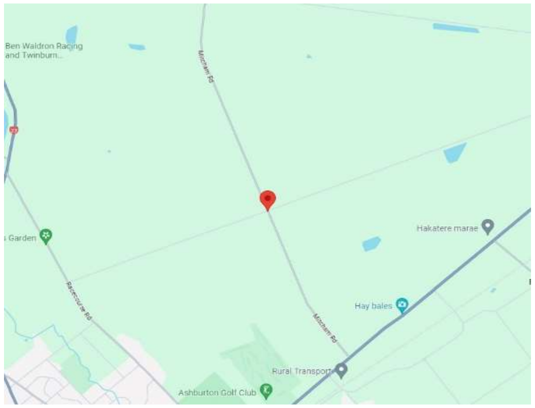



Ashburton District: **Straight Flat Crossroad**

Intersection of Hepburns Road (yielding) and Mitcham Road.

- Flat geography
- Priority road difficult to see
- Visual continuity (hedging)
- Long straight with Hepburns having priority on prior intersections

*Previous crash site highlighted by industry experts.*

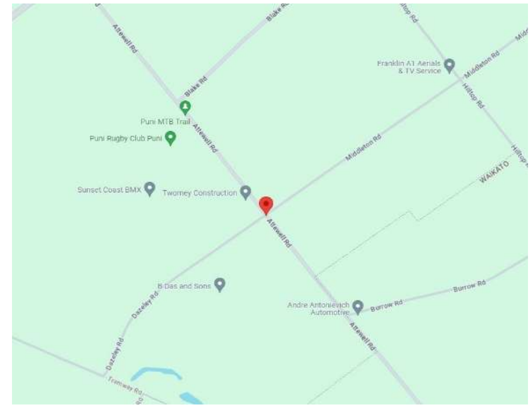


Auckland District: **Downhill Approach Crossroad**

Intersection of Middleton Road (yielding) and Attwell Road.

- Moderate downhill slope
- Priority road difficult to see
- Sense of visual continuity
- Middleton Road had priority at prior intersections

*Previous crash site identified in CAS analysis.*

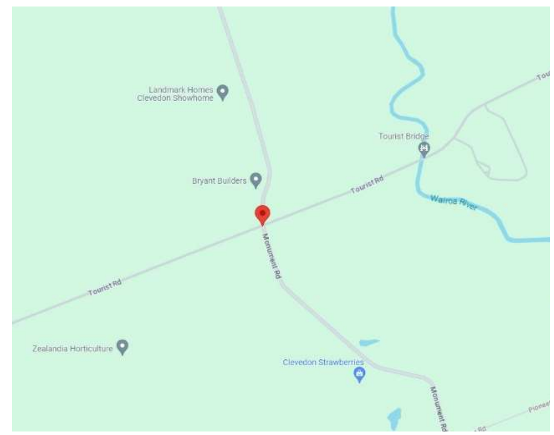



Auckland District: **Uphill Approach Crossroad**

Intersection of Tourist Road (yielding) and Monument Road.

- Moderate uphill slope
- Priority road difficult to see
- Considerable vegetation on approach to crossroad

*Identified as high risk and intervention installed by Auckland Transport.*



### *Crossroad mitigation design*

The project team used existing work on potential rural crossroads safety interventions (Luther et al., 2021), gathered the views of industry experts, and considered the results of Phase 1 of this work to identify low-cost safety interventions that would be feasible to implement broadly at rural crossroad sites. The team then set about developing mitigations that included many of these interventions.

A set of design criteria that mitigations must meet to be used in the trial was developed based on relevant literature, road safety expert advice, a case study review of four existing treated sites, and a review of an Auckland Transport analysis of the effectiveness of transverse lines on minor approaches to intersections with 200m warning signs. The design criteria were:

1. Catch a drivers' attention well in advance of the crossroad and encourage drivers to move from autopilot into proactive scanning.
2. Provide multiple opportunities to catch the drivers' attention, rather than relying on one point in time (as a single sign does).
3. Provide cues that are in the drivers' mostly likely field of view so that their attention is likely to be captured (assuming they will often be looking up and forward down the road into the distance where the road appears to continue).
4. Have strong daytime conspicuity (many crashes identified occurred during the day).
5. Provide drivers with additional, unambiguous, information about the road ahead (such as a stop warning symbol or stop ahead text).
6. Utilise readily available Traffic Control Devices (TCDs)[3] where possible, so as to be cost-effective and practical to roll out broadly and maintain over the longer term if successful.
7. Ideally, create a feeling that the driver should slow down, a visual pinch point/narrowing of the roadway ahead. This could partially be achieved by gated stop warning signs. A stronger sense of narrowing could be achieved through paintwork, retro-reflective raised pavement markers (RRPMs) or similar.

Mitigations that met these criteria were designed by the project team and reviewed by road safety experts. The final agreed designs are presented on the following page. All of the interventions are TCD compliant with the exception of the Stop warning signs in Mitigation 2. As far as the research team are aware, backing boards are not approved for use as part of warning signs at rural crossroads. However, these signs were selected because they were already in use at the Tourist Road Monument crossroad (one of the sites selected for inclusion in the trial) which suggested that they were feasible to implement. However, they are not a common sign design, and it was of interest to test the effect of an unfamiliar sign on driver detection of the approaching crossroad.

Figure 5 details each mitigation condition, Figure 6 shows an example of mitigations created through video augmentation at one site. For standard treatments, additional signage and markings were digitally removed from the video to achieve the specifications in Figure 5. However, centreline markings were retained as they were videoed onsite because, depending on the nature of the road, approaches to crossroads may, or may not, have centrelines present. The team wished to have both options included in the trial.

[3] TCDs are signs, markings, and other interventions that have been approved by the relevant authorities for use on New Zealand roads.

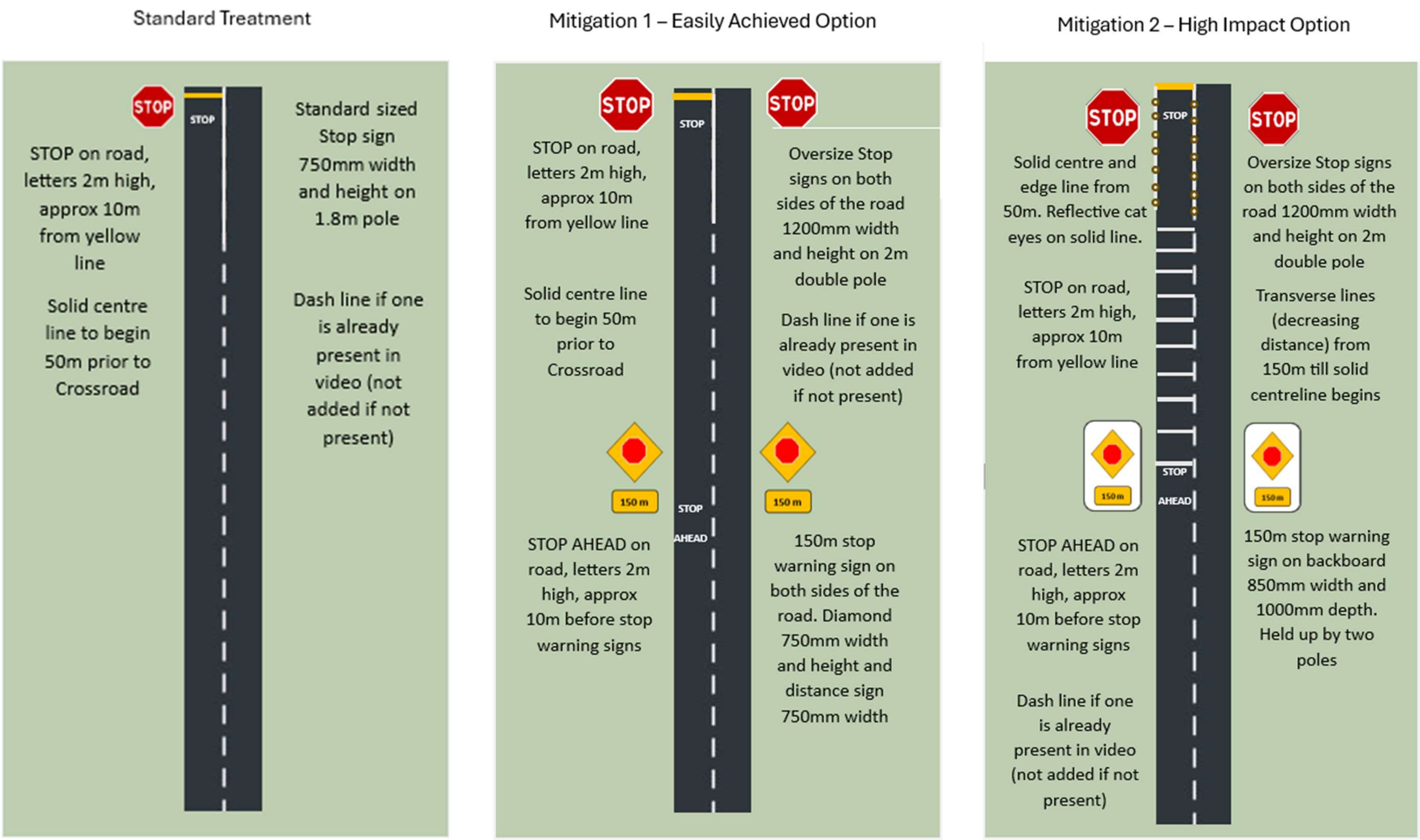



*Figure 5: Crossroads trial conditions.*


*Figure 6: Example of video augmentation and mitigations at crossroads site.*

### *Trial Procedure*

Sixty participants, recruited by a specialist recruitment company, took part in the mitigation trial. The recruitment process was structured so that the final sample of participants was balanced in terms of gender, age, and those that drove on rural roads rarely versus frequently. Each participant was briefed on the trial, gave their consent, completed a reaction time task, received training prior to completing the trial, and an incentive afterwards.

The trial included 12 video conditions, four roads were presented with each of the three crossroad treatments (standard treatment, Mitigation 1, and Mitigation 2). Each video was approximately 3 minutes long and showed the vehicle approaching and going through the crossroad.

While viewing the video, participants were asked to provide a verbal commentary of what they were seeing in the road environment (verbal protocol) and to press the space bar on the keyboard each time *they recognised that they needed to stop or give way ahead*.

The verbal protocol helped the team understand what aspects of the environment were salient to participants and having them press the space bar enabled the team to test how far from the crossroad participants were able to detect that they needed to stop or give way. Figure 7 shows a participant completing the mitigation trial.

A between-subjects design was used so that all participants saw each road once, and each mitigation at least once. This meant that, in total, 20 participants saw each crossroad by mitigation condition. Across all conditions, and participants, 240 individual reactions were measured. Participants also viewed 'filler' videos that didn't contain treated crossroads, but included roundabouts and other treatments that required them to stop or give way.

After the video component of the trial finished, participants completed a questionnaire that asked for their views on each component intervention included in the mitigations (e.g. the oversize Stop signs). Participants were also asked to 'trade off' between interventions indicating which they felt were the most impactful and why.

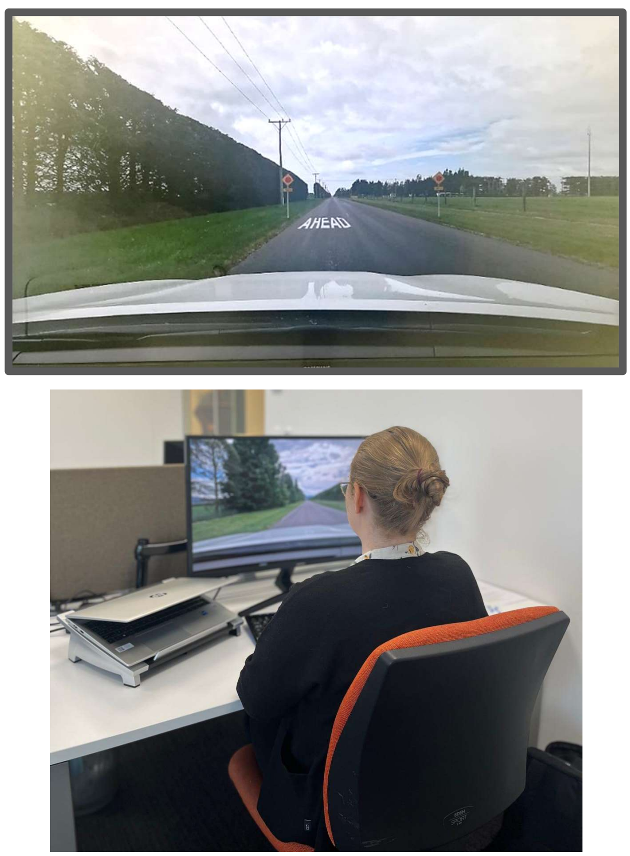



*Figure 7: Participant view when completing the mitigation trial.*

### *Trial Analysis*

Following trial completion, participant responses were reviewed to ensure that they had completed the task as instructed (e.g., not pressing the spacebar outside of the time when the crossroad could be seen, or pressing when they would have begun braking). The verbal protocol and data log were used to make these checks.

Responses were reviewed to check participants were completing the instructed task (e.g., not guessing, then later confirming without pressing again, or performing braking behaviour). The verbal protocol and log data were used to confirm if outliers were completing task correctly.

Of the 240 responses, 27 individual responses were removed (including all four from one respondent who was eliminated from the trial). Table 2 shows the number of individual responses included in the analysis for each mitigation at each site.

*Table 2: Number of individual responses included in the analysis*

| Site name | Baseline | Mitigation 1 | Mitigation 2 |
|---|---|---|---|
| Hedge lined flat x-road | 16 | 19 | 16 |
| Straight flat x-road | 16 | 19 | 18 |
| Downhill approach x-road | 17 | 18 | 20 |
| Uphill approach x-road | 18 | 16 | 17 |

The cleaned dataset for each site was sufficient to undertake statistical testing. Descriptive summary values included calculating medians and confidence intervals for each mitigation at each site.

Significance testing (t-test) was completed with a cut of p-value<0.01 with a Bonferroni correction as significant (due to multiple testing). This set the significance value to 8.33E-4. This provided a 99% confidence of a difference between two mitigations.

It should be noted that during analysis, a minor error was noted in the placement of the warning sign on the downhill approach crossroad (Middleton Attwell). The warning sign was placed 30-50m closer to the intersection than intended. The result was that it was seen slightly later (2-3 seconds) by participants than intended. Despite this, a significant effect was still seen for the site. Had the sign been placed in the correct location we would have expected an even stronger result. However, given the already high strength, it would not have changed the findings, conclusions, or recommendations.

# 4. CRASH DATA ANALYSIS RESULTS

The purpose of the crash data analysis was to build insights into the frequency of 'failed to detect' crashes at rural crossroads, and the system factors associated with them.

The primary source of information for the analysis was NZTA CAS reports. These were supplemented with SCU reports, Coroners reports and Google Maps images where available. The following section outlines the findings from this analysis.

## 4.1. Comparison of intersection crashes

A broad analysis of crashes at all rural intersection types identified in the CAS search was first undertaken to establish whether rural crossroads have a similar profile of crash causes to other intersection types (e.g., T junctions).

As stated in the method section, all identified rural intersection crashes were reviewed and, where there was sufficient information, a project team review coded them as either:

a) Yielding driver failed to detect the intersection

b) Yielding driver failed to give way to oncoming traffic

c) Yeilding driver error (unknown)[4]

d) Other (e.g., a vehicle on the priority road turning right into oncoming traffic)

Figure 8 shows the comparison of crash causes between crossroads and other intersection types.

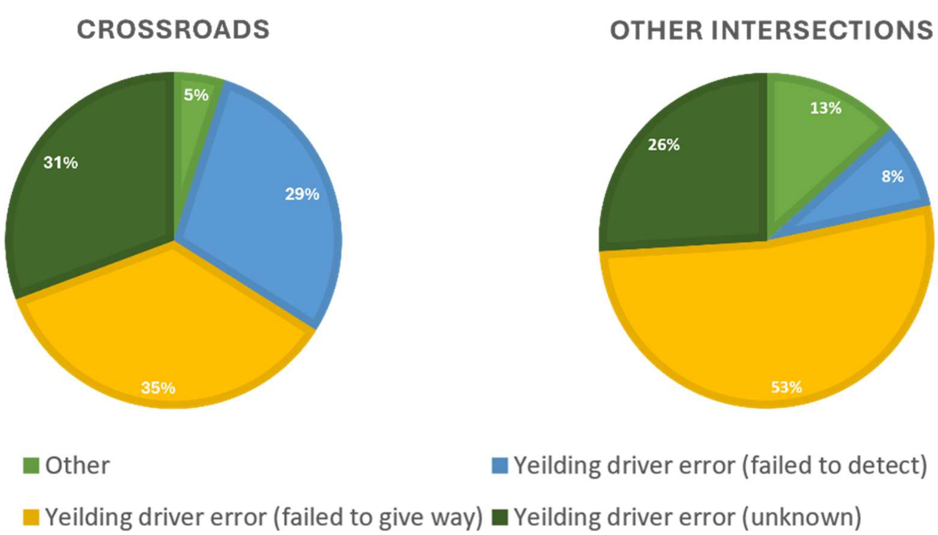



*Figure 8: Crash causes at crossroads compared to other intersections.*

[4] This classification meant that the reviewer could see that the crash was caused by a yielding driver error. However, the information in the CAS report and any other available information was insufficient to assess whether the driver had failed to detect the crossroad or failed to give way.

It should first be noted that of all rural intersection crashes identified in the dataset, a substantial number were found to be the fault of the yielding driver, but the specific crash cause could not be ascertained from the available information. Information in CAS reports is relatively limited, particularly when those involved have been seriously injured or killed. Often classification relied on the comments/observations of witnesses, attending officers, or passengers and the reviewers took a conservative approach by not classifying the crash if they could not be reasonably confident about the information provided.

Results for crashes where sufficient information was available to code a crash cause show that ‘failure to detect’ crashes do occur at all intersection types. This dataset only included fatal and serious crashes. It is likely that more, less serious, ‘failure to detect’ crashes also occur at rural intersections or that failing to detect the crossroad results in no crash because an intersecting vehicle isn’t approaching by chance.

A comparison between crossroads and other rural intersections shows that many more ‘failed to detect’ crashes occur at rural crossroads (29% of crashes reviewed compared to 9% for other intersections). This suggests that there are some features of rural crossroads that make these types of crashes more likely. To better understand the characteristics of ‘failure to detect’ crashes at rural crossroads, a more detailed Safe System/ Human Factors analysis was undertaken. The results are presented in the following section.

## 4.2. Features of ‘failed to detect’ crossroads crashes

A total of 42 ‘failed to detect’ crossroads crashes were identified in the CAS dataset. After a more detailed review of these crashes, a further two were removed from the analysis. This was because they involved sites with railway tracks and may have involved driver distraction/confusion with the road layout. The results of the detailed review of the remaining 40 ‘failed to detect’ crossroad crashes are provided below.

### *Crash locations*

As Figure 9 shows, ‘failed to detect’ crossroad crashes occurred throughout New Zealand. However, there were a notably large number in the Canterbury region. Given the geography of the area, with many crossroads, this is most likely due to increased driver exposure to this type of road layout in Canterbury.

In terms of road type, the majority of crashes occurred on medium or minor rural roads (32) with only a few occurring on major rural roads (5) or rural arterials (3). This suggests that crashes are occurring on roads with lower volumes of traffic, likely without the visual cues of intersecting traffic ahead. Potentially, these roads may also be less likely to have additional treatments (such as signage and markings) as they may not be considered high risk.


| | |
|---|---|
| Auckland Region | 4 |
| Bay of Plenty Region | 1 |
| Canterbury Region | 21 |
| Hawke's Bay Region | 1 |
| Manawatu-Whanganui Region | 3 |
| Otago Region | 1 |
| Southland Region | 3 |
| Tasman Region | 2 |
| Waikato Region | 4 |
| Total | 40 |

*Figure 9: Location of 'failed to detect' crossroads crashes*

### *General environment*

One factor potentially implicated in 'failed to detect' crashes is drivers travelling on long straight roads where they have had right of way at previous intersections, losing attention, and travelling on autopilot. In these cases, drivers might be less likely to notice road markings and signage warning them of an intersection ahead. This issue was raised by road safety experts in several of the SCU reports reviewed as part of this project. It was therefore of interest to establish whether this type of environment was common in the 40 'failed to detect' crashes reviewed.

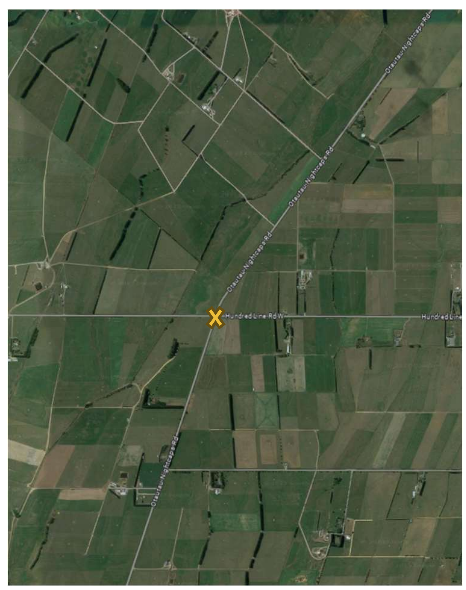


*Figure 10: Example of 'simple' surrounding geography*

Interestingly, crash report reviewers classified the surrounding geography as relatively simple in all 40 crashes (few junctions, corners, or other complexities). They also found that in 31 of the 40 crashes, the yielding driver had priority at the intersection they had travelled through prior to the crash (or the intersection had no clear priority).

The weather at the time of most crashes (34) was fine or overcast, and most occurred during the day (33) and on dry road surfaces (34). These results indicate that visibility wasn't impaired by weather conditions or lack of daylight.

### *Road geometry*

The road environment at the crossroad itself is also a potential factor in 'failure to detect' crashes, for example, if the priority road is difficult to see, or the road appears visually to continue on straight ahead.

In the case of the 40 crashes reviewed, reviewers made the following assessments (based primarily on judgements from Google Street View):

- In 35 cases, the yielding approach road gradient was flat (three were on slight up hills and two were on slight downhills).
- In 35 cases, the yielding approach road was straight.
- In 31 cases, the skew of the yielding road after the crossroad appeared to be less than 5 degrees (the road appeared visually to carry on ahead).
- In 31 cases, the priority road was somewhat or very difficult to see from the yielding road approach (hidden by hedgerows, fences, long grass, banks etc.).
- In 17 cases, the surrounding roadside provided additional continuity cues suggesting the yielding road continued ahead uninterrupted (such as continuing treelines). See Figure 11 for example of continuity cues.

These results clearly suggest that, in terms of road geometry, there are specific conditions under which failing to detect a crossroad is more likely. When combined with the broader general environmental results described previously, which may lead a driver to be less attentive, a picture emerges of the situations under which errors are more likely.

*Figure 11: Example of continuity cues (hedge) at a site in Canterbury*

### *Road markings and signage*

Given the nature of the crashes under consideration, it was of interest to establish the nature and condition of road markings and signage at the crossroads where crashes had occurred. This provides information about whether crashes are associated with failure to implement signage and markings that meet minimum standards,[5] or failure to maintain signage and markings.

It should be noted that signage and marking was primarily assessed based on comments of attending officers at crashes (which were infrequent) or using Google Street View. However, Google Street View only provides intermittent images of a site. Therefore, these results are the best assessment possible by the reviewer given the information available.

Of the 40 crashes reviewed, the reviewer assessed that in 39 cases, signage met minimum standards and, in all cases, markings met minimum standards. In one case, a sign was missing from Google Street View, but it could not be confirmed whether this was the case when the crash occurred. The reviewer also considered that all signs and most markings appeared in adequate condition.

At many sites (25), additional signage was confirmed as present before the crash occurred, these included a single warning sign before the crossroad (16), gated warning signs before the crossroad (6), flashing warning signs (2), and gated signs at the crossroad (7). Some sites included more than one of these interventions. In a few cases, crash sites also included painted transverse lines (4) or a painted Stop (3) to alert drivers to the crossroad.

Again, it should be noted that we cannot be sure that all of these interventions were present at the time of the crash due to limited information as described above. However, the results do suggest that, by themselves, warning signs and markings do not always succeed in alerting drivers to the upcoming crossroad, particularly single warning signs which may present in a drivers' field of view for only a short time.

### *Drivers*

Driver behaviour, particularly inattention and autopilot behaviours, have been identified by some road safety experts as a potential factor in 'failure to detect' crashes. While specific information about driver behaviour is often very limited in CAS reports, reviewers examined driver demographics and other information that was available.

Interestingly, in all cases (except one that was miscoded), the CAS report indicates that the yielding driver direction of travel was straight through the crossroad (movement code HA). This appears consistent with drivers expecting the road to continue on ahead.

The yielding drivers involved in the crashes reviewed ranged in age from 18-83 years old, although most were in the 20s and 30s. Male drivers were more commonly involved as yielding drivers (29) than females (11), although this may reflect that males more frequently drive in rural environments (exposure). Most drivers held a full NZ licence. There was insufficient information in the CAS reports to confidently calculate how many drivers held a foreign licence, although the narratives suggested that a few did.

Reviewers also considered whether the description of the crash was more suggestive of a slip/mistake on the part of the yielding driver, or a violation such as speeding or alcohol/drugs. While all of 'failure to yield' crashes are ultimately a slip/mistake in that the driver didn't detect the crossroad, other factors identified also included distraction (9), unfamiliarity with the area (11), and speed (10). Violation type behaviours were not

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[5] Minimum standard was considered to be a single Stop or Give Way sign at the crossroad accompanied by a painted yellow yield line.

common. Alcohol was noted as suspected on many CAS reports, however, the team suspect that this field isn't reliable in CAS. Examination of accompanying SCU reports didn't identify alcohol as a common issue, and issues with alcohol-related crash data were identified in report by Harris et al., 2022.

The review of SCU reports for five crashes provided further information around driver unfamiliarity with the area/being lost, use of phones/navigation devices, and distraction due to passengers. While broad conclusions cannot be drawn from these, they do suggest a greater risk of failing to detect a crossroad when drivers attention is drawn by navigation tasks and other in-car distractions. Due to the limitations of CAS reports, this isn't fully evident in the larger dataset, but this may be due to data deficiencies.

### *Factors implicated in 'failed to detect' crossroads crashes*

Looking across all the factors considered during the review of 40 'failed to detect' crossroads crashes, the following appear to be commonly implicated:

- Specific geographic areas, particularly Canterbury. This is likely to be because of the frequency of rural crossroads and surrounding environment.
- Minor or medium rural roads.
- Relatively simple surrounding environments (long straights, little traffic, few corners etc.) and situations where yielding drivers have previously had priority.
- Crossroads where the yielding approach is straight, flat and continues fairly straight following the crossroad.
- Crossroads where the priority road is difficult to see from the yielding road (often due to ditches, fences, or high grass on the main road).
- Driver unfamiliarity with the area and distraction (in some cases due to using navigation devices).
- Driver speed.

In terms of underlying factors, the nature and circumstances of some crashes appear to suggest that driver expectancy may play a role. The nature of the environment (low complexity) may encourage driving without awareness/autopilot behaviours. With few cues to indicate the crossroad ahead, they may not have been 'snapped out' of their inattention sufficiently to alert them to the upcoming crossroad.

Conversely, other crashes suggest that distraction and attentional narrowing may have been a factor. For example, drivers may have needed to allocate attentional resources to navigation in an unfamiliar environment. With few cues to indicate the crossroad ahead, their attention may not have been drawn away from their task sufficiently to alert them to the upcoming crossroad.

In both of these attentional states (driving without awareness and distraction), drivers can 'fail to see' important traffic information such as road signs (attentional blindness). These attentional errors may be why the additional signage and markings identified during the review hadn't worked in some of the crashes.

The information gathered during this crash review provides some clear direction for the development of mitigations, suggesting that they need to need to catch drivers' attention and 'snap them out' of their expectations into a more conscious proactive style of driving. It also suggests that a single presentation, such as a warning sign, may be insufficient because they provide a limited opportunity to capture attention.

The following section describes the mitigation trial undertaken as part of this project. The mitigations developed and tested were created with consideration to the results of this crash analysis.


Stuff.

# 5. MITIGATION TRIAL RESULTS

The purpose of the mitigation trial was to design and test several efficient, cost-effective mitigations for ‘failure to detect’ crashes at New Zealand rural crossroads. It was intended that these mitigations could be feasible to roll out broadly across the road network, following an assessment and implementation methodology, if successful.

The goal was to better understand what types of routinely available signage and markings are visible and attention-grabbing for yielding drivers on the approach to a rural crossroad typical of those where ‘failure to detect’ crashes have been found to occur.

Sixty participants enrolled and completed the mitigation trial which was conducted as described in Section 3.2. The demographic profile of participants is provided in Appendix A.

The following sections provide the trial results. The findings across all sites are presented, followed by a specific examination of each site and information on participants views about individual interventions (e.g., the oversize Stop signs).

## 5.1. Key findings across all trial sites

Table 3 shows that at three sites, participants indicated that they knew that they needed to stop or give way ahead significantly earlier when Mitigations 1 or 2 were presented, compared to the baseline condition. This result highlights the importance of advanced warning signage and possibly also oversize gated Stop signs.

*Table 3: Seconds before intersection participants knew they needed to stop or give way ahead and significance testing between mitigations. Significant values shown in Green.*

| | Median (confidence interval) | | | Significance test (p-values) | | |
|---|---|---|---|---|---|---|
| **Site Name** | Baseline | Mitigation 1 | Mitigation 2 | Baseline – Mitigation 1 | Baseline – Mitigation 2 | Mitigation 1 - Mitigation 2 |
| hedge lined flat x-road | 9.08 (8.03 – 11.27) | 14.29 (12.15 – 14.79) | 13.31 (12.66- 14.27) | $9.7 \times 10^{-5}$ | $2.2 \times 10^{-4}$ | $1.9 \times 10^{-1}$ |
| straight flat x-road | 10.24 (9.73 -12.40) | 15.63 (15.03 -17.03) | 17.01 (14.61 – 17.73) | $2.6 \times 10^{-7}$ | $8.4 \times 10^{-6}$ | $4.4 \times 10^{-1}$ |
| downhill approach x-road | 9.85 (8.82 – 11.06) | 15.49 (13.85 – 16.67) | 14.45 (12.89 – 15.59) | $1.0 \times 10^{-6}$ | $1.2 \times 10^{-5}$ | $1.4 \times 10^{-1}$ |
| uphill approach x-road | 11.60 (10.16 – 12.52) | 13.42 (11.74 – 15.19) | 12.20 (11.15 – 13.93) | $2.8 \times 10^{-2}$ | $1.0 \times 10^{-1}$ | $2.1 \times 10^{-1}$ |

The importance of advance warning signs is further highlighted by the results presented in Figure 12. For this analysis, the key press, giving the time when a participant knew they needed to stop or give way, has been converted into distance from the crossroad using an assumed travel speed of 100km/h.

A danger zone for identifying the need to stop or give way was calculated. This was the point (in distance) at which a driver in a real-world setting would have to brake hard to stop in time for the crossroad. The danger zone was defined as 100m prior to the crossroad or closer. This was based on an approach taken by Queensland Australia road controlling authorities[6]. Any driver who indicated that they needed to stop or give way after this point may be at high risk of failing to stop in a real-world setting, depending on existing levels of distraction or disengagement with their surrounding environment.

Figure 12 shows, **at all sites under the baseline condition, some participants identified that they needed to stop or give way within the danger zone**. In the case of the hedge lined flat crossroad (site near Ashburton), seven participants (44%) didn't identify that they needed to stop until within the danger zone.

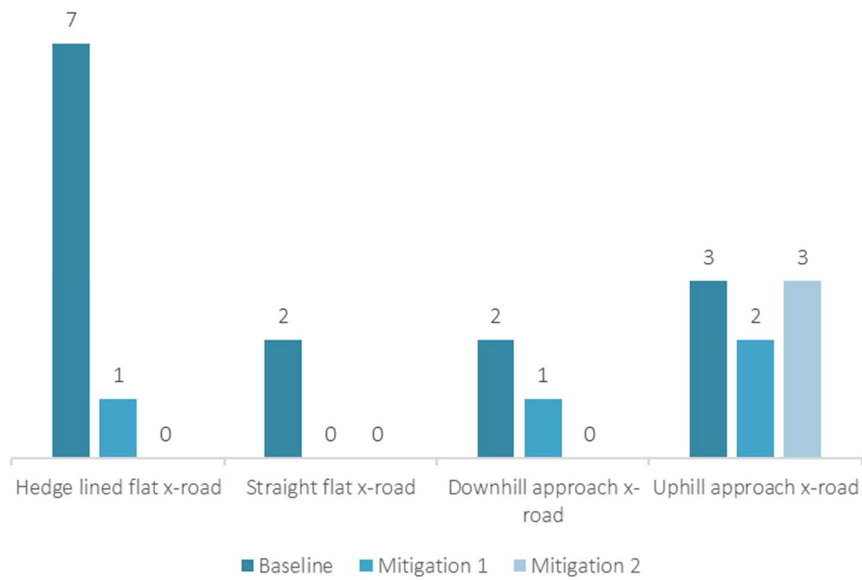


*Figure 12: Number of participants who indicated they needed to stop or give way within the 'danger zone' of less than 100m prior to the crossroad.*

This is quite concerning, particularly given that, because they were instructed to press a key when they knew they needed to stop or give way, participants completing this trial are probably more likely to be alert and scanning the environment than real-world drivers in some circumstances. For example, no participants had the opportunity to be distracted by a passenger or mobile phone.

Across three of the four sites, the inclusion of Mitigations 1 and 2 reduced the number of participants identifying that they needed to stop or give way in the danger zone. However, at the uphill approach crossroad this reduction wasn't achieved.

A more detailed discussion of the results for each individual site is provided in the following sections.

[6] Based on information provided in: Stopping distances: speed and braking | Transport and motoring | Queensland Government (www.qld.gov.au).

## 5.2. Hedge lined flat crossroad (Dromore Methven Rd yielding and Mitcham Rd, Ashburton)

This site has many of the characteristics of sites where ‘failure to detect’ crossroad crashes were identified during the crash data analysis. The yielding approach is flat and straight for a long distance, the priority road is buried in the landscape and obscured by a hedgerow making it difficult to detect. This hedgerow also provides visual continuity cues suggesting the yielding road continues without interruption, and minimal road signage at the crossroad is difficult to see against the green treed background (Figure 13).

Figure 14 shows the distance from the crossroad that participants indicated, through a spacebar press, that they knew they needed to stop or give way ahead. The yellow line provides the location of the warning signs that were present in the video for both mitigations and the black lines show distances to the crossroad.

Interestingly, in the baseline condition, seven participants were within 100m of the crossroad when they indicated that they knew they needed to stop or give way (defined as the danger zone). Based on a review of the video for this site, it seems likely that the dull cloudy weather, combined with the Stop sign being positioned against a dark treeline made the Stop sign difficult for participants to detect. This result highlights the variable effectiveness of existing standard mitigations at crossroads under certain environmental conditions.

As Figure 14 shows, both mitigations had the desired effect of moving back the distance where participants indicated that they knew they needed to stop or give way to a safe distance from the crossroad in almost all cases (only 6%, one participant, was within the 100m danger zone for Mitigation 1). Interestingly, there was little difference in the effectiveness of the two mitigations. This is even though Mitigation 2 is more visually obtrusive. This result suggests that in normal driving conditions standard warning signs and oversize stop signs may be sufficient to alert most drivers to the presence of the crossroad.

*Figure 13: Photograph of crossroad as it currently appears in real life.*

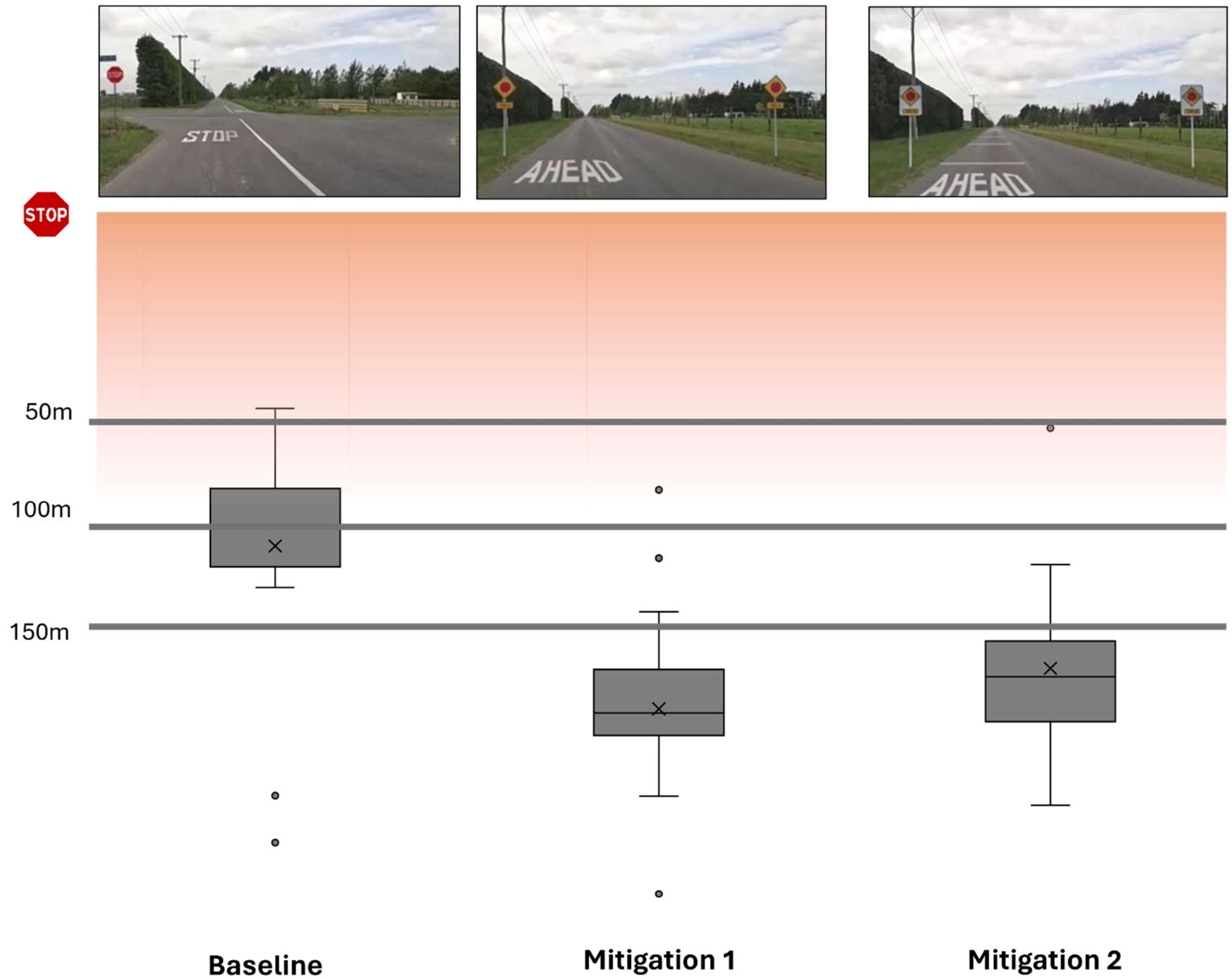


*Figure 14: Box and whisker plot showing where (in distance) participants understood there was an intersection ahead at Dromore Mitcham, with approximate distances from the intersection super imposed. X's show the median, and outliers are plotted. Note: actual measurements were in seconds from the intersection, however, the distances are shown to better contextualise the results.*

## 5.3. Straight flat crossroad (Hepburns Rd yielding and Mitcham Rd, Ashburton)

This site, a straight flat road in Ashburton (Figure 15), was the site of a serious 'failed to detect' crash in 2019. At the time, the site only had a Give Way sign at the crossroad with no warning signs. The site has many of the characteristics of sites where 'failure to detect' crossroad crashes were identified during the crash data analysis. It is flat and straight, with a strong sense of the yielding road continuing through the crossroad without interruption. The priority road is partially obscured in the landscape due to a hedgerow on the right and because the geography is very flat. The road signage is somewhat difficult to see against the background.

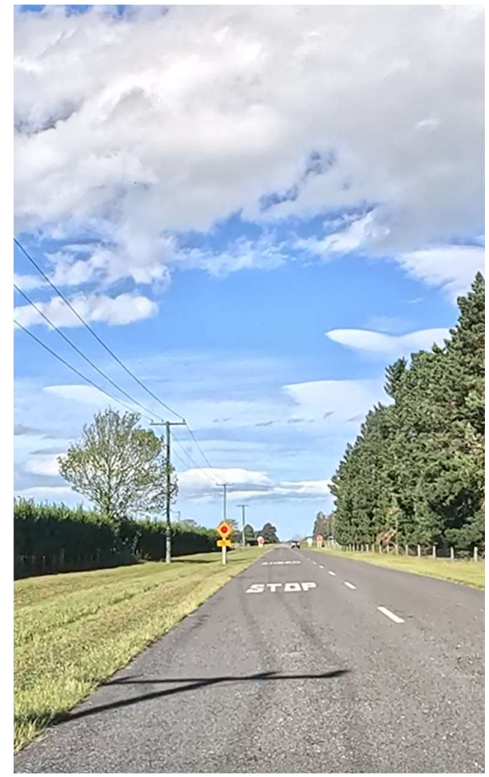


*Figure 15: Photograph of the crossroad as it currently appears in real life.*

Figure 16 (following page) shows the distance from the crossroad that participants indicated, through a spacebar press, that they knew they needed to stop or give way ahead. As with the previous figure, the yellow line provides the location of the warning signs that were present for both mitigations and the black lines show distances to the crossroad.

In the baseline condition, two participants indicated that they only knew they needed to stop or give way within 100m of the crossroad (the danger zone). This is less than at the hedge lined flat crossroad site (also in Ashburton). This may be because the Stop sign was not overlayed against a treeline and stood out more against the skyline which was sunny and clear. However, as stated previously, given the task was performed under experimental conditions, where participants are likely to be alert and attentive, it is somewhat concerning that any participants would recognise they needed to stop or give way this late.

Figure 16 also shows that both mitigations were successful at moving the distance where participants knew they needed to stop or give way back away from the crossroad (0% within the 100m danger zone). At this site, Mitigation 1 appeared to achieve more consistent results. This indicates that in normal driving conditions (daylight and good weather) standard warning signs and oversize stop signs may be sufficient to alert most drivers to the presence of the crossroad.

In addition, the results may highlight the impact of unfamiliar signage on driver understanding of the road ahead. Given the obtrusive nature of Mitigation 2, it is possible that some participants were aware of the signs some time before they realised that they indicated that they should stop or give way. If this is the case, while the signs attracted attention, they may also have served as something of a distraction while participants worked out what they meant.

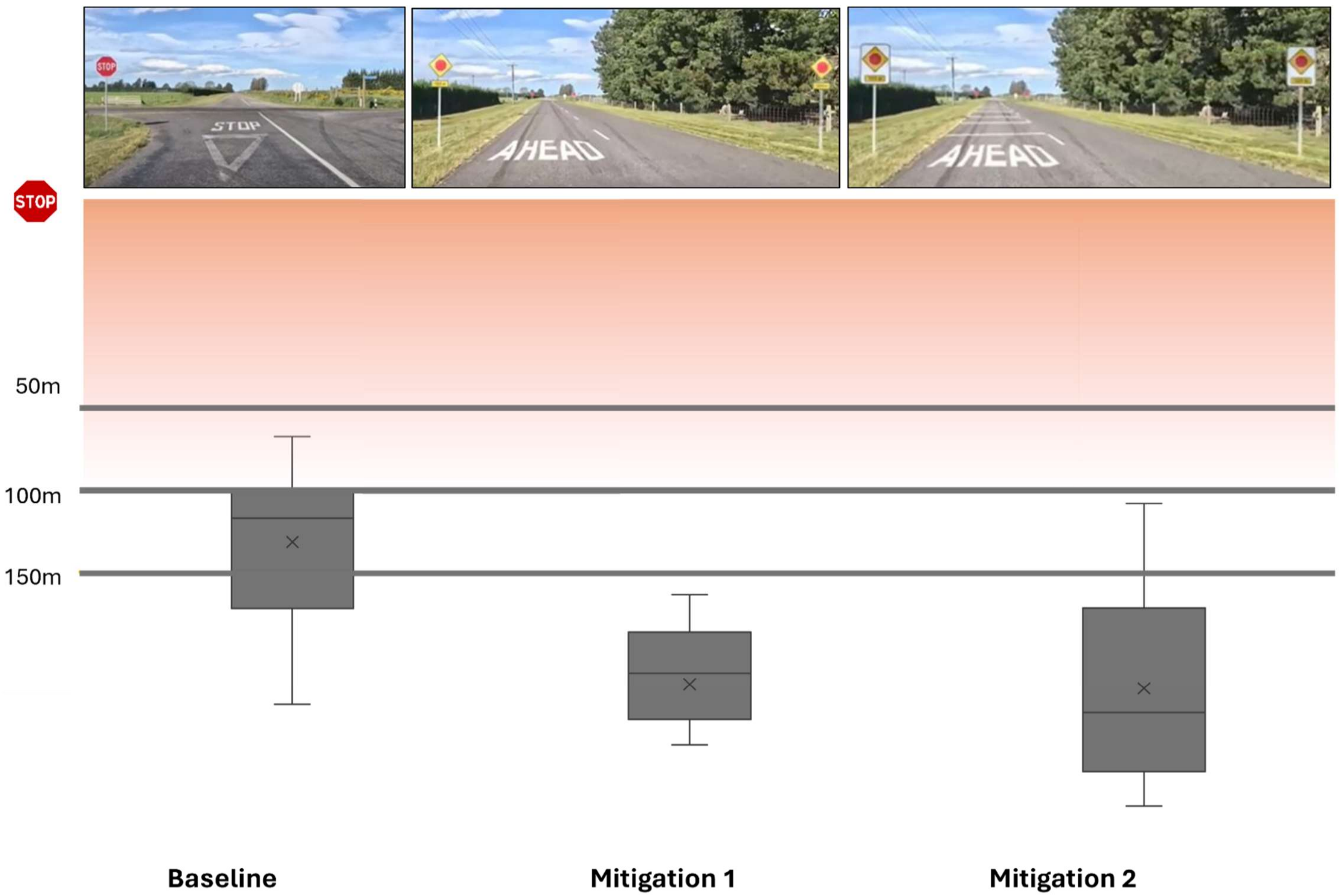


*Figure 16: Box and whisker plot showing where (in distance) participants understood there was an intersection ahead at Hepburns Mitcham, with approximate distances from the intersection super imposed. X's show the median, and outliers are plotted. Note: actual measurements were in seconds from the intersection, however, the distances are shown to better contextualise the results.*

## 5.4. Downhill approach crossroad (Middleton Rd yielding and Attwell Rd, Auckland)

This Auckland site with its steady downhill slope to the crossroad is less typical of sites where 'failure to detect' crashes have occurred. However, it does have some of the typical features: the road is straight, has a sense of continuity beyond the crossroad, and the priority road is difficult to see as it is buried in the landscape due to banks and hedgerows. Additionally, this site has some signage typical of crossroads, such as speed limit signs which only reinforce continuity (see Figure 17). The yielding road also had priority at previous intersections. Interestingly, in 2018, a 'failure to detect' crash occurred at this site. At the time, there was a single Stop sign at the crossroad and no warning signs.

*Figure 17: Photograph of the crossroad as it currently appears in real life.*

Figure 18 shows the distance from the crossroad that participants indicated, through a spacebar press, that they knew they needed to stop or give way ahead at the downhill approach crossroad site.

The results at baseline for this site show a similar pattern to other sites with two participants indicating that they knew they needed to stop or give way within the 100m danger zone. When the site is viewed at a distance, the baseline Stop sign was superimposed on a relatively complex background including powerlines, houses, trees, and commercial buildings. This may have made the signs less obtrusive than they might be against a plainer background such as a skyline.

Figure 18 also shows that, as with the first two sites, both mitigations were successful at moving the distance where participants knew they needed to stop or give way back away from the crossroad (only 6%, 1 participant, was within the 100m danger zone for Mitigation 1).

Overall, Mitigation 1 was more effective than Mitigation 2.[7] As mentioned previously, it may be that the novelty of the signs in Mitigation 2 attracted participants attention but didn't provide them with sufficient information to know they needed to stop or give way until closer to the crossroad. This highlights the dichotomy of using unusual signage, it likely attracts driver attention but doesn't impart information about the road ahead as efficiently as familiar signs.

[7] As mentioned previously, the warning signs for both Mitigations 1 and 2 were placed 30-50m closer to the crossroad than intended. While the results were still significant, had they been correctly placed, the effect of the mitigations (compared to baseline) may have been even stronger.

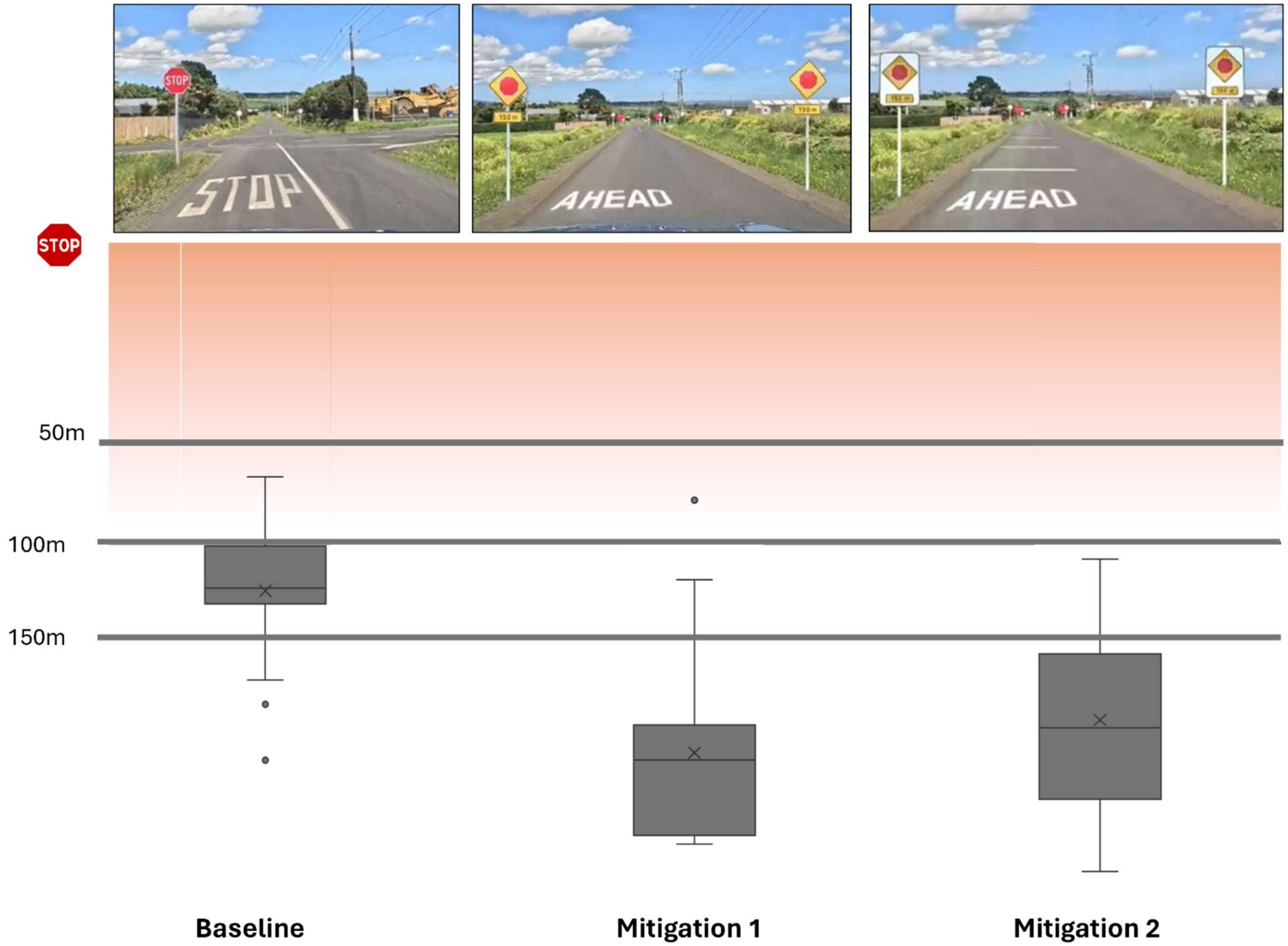


*Figure 18: box and whisker plot showing where (in distance) participants understood there was an intersection ahead at Middleton Attwell, with approximate distances from the intersection super imposed. X's show the median, and outliers are plotted. Note: actual measurements were in seconds from the intersection, however, the distances are shown to better contextualise the results.*

## 5.5. Uphill approach crossroad (Tourist Rd yielding and Monument Rd, Auckland)

This Auckland site has a steady uphill slope with the crossroad being positioned on the brow of the hill and invisible from the yielding road. The crossroad was less typical of sites where ‘failure to detect’ crashes have occurred, in that the yielding road didn’t appear to continue beyond the crossroad because it disappeared over the hill brow. Interestingly, at the time of filming, interventions had been placed at this site to increase the conspicuity of the crossroad (see Figure 19), suggesting that the site has already been considered risky. The additional signs and markings were digitally removed before adding the trial mitigation conditions.

Figure 20 shows the distance from the crossroad that participants indicated, through a spacebar press, that they knew they needed to stop or give way ahead at the uphill approach crossroad site.

In the baseline condition, three participants indicated that they only knew they needed to stop or give way within the 100m danger zone. This is slightly higher than two of the sites, but lower than the tree lined flat crossroad in Ashburton. Interestingly, both this site and the Ashburton site were filmed on cloudy days and at both sites the signage was superimposed on a treeline. This may be why both had greater numbers of people identifying the crossroad within the danger zone.

Figure 20 also shows that, at this site, neither Mitigation 1 or 2 were successful in moving the distance where participants knew they needed to stop or give way further away from the crossroad. This is a notable difference from the previous three sites. When considering why a different effect was achieved, the team noted a number of factors:

1. Warning signage was set against the rise leading up to the crossroad which meant they were viewed against a heavy tree line.
2. The tree line along the top of the ridge has gaps with light shining through that may have attracted attention away from the warning signage.
3. The right-side oversize stop signs (included in both mitigations) was obscured by trees from the view of the yielding driver. These signs may be a key part of the mitigation. It is possible that the lack of visibility of this component of the mitigation resulted in participants being unsure of the intent of the warning sign until they were much closer than at the other sites.


*Figure 19: Photograph of the crossroad as it currently appears in real life.*

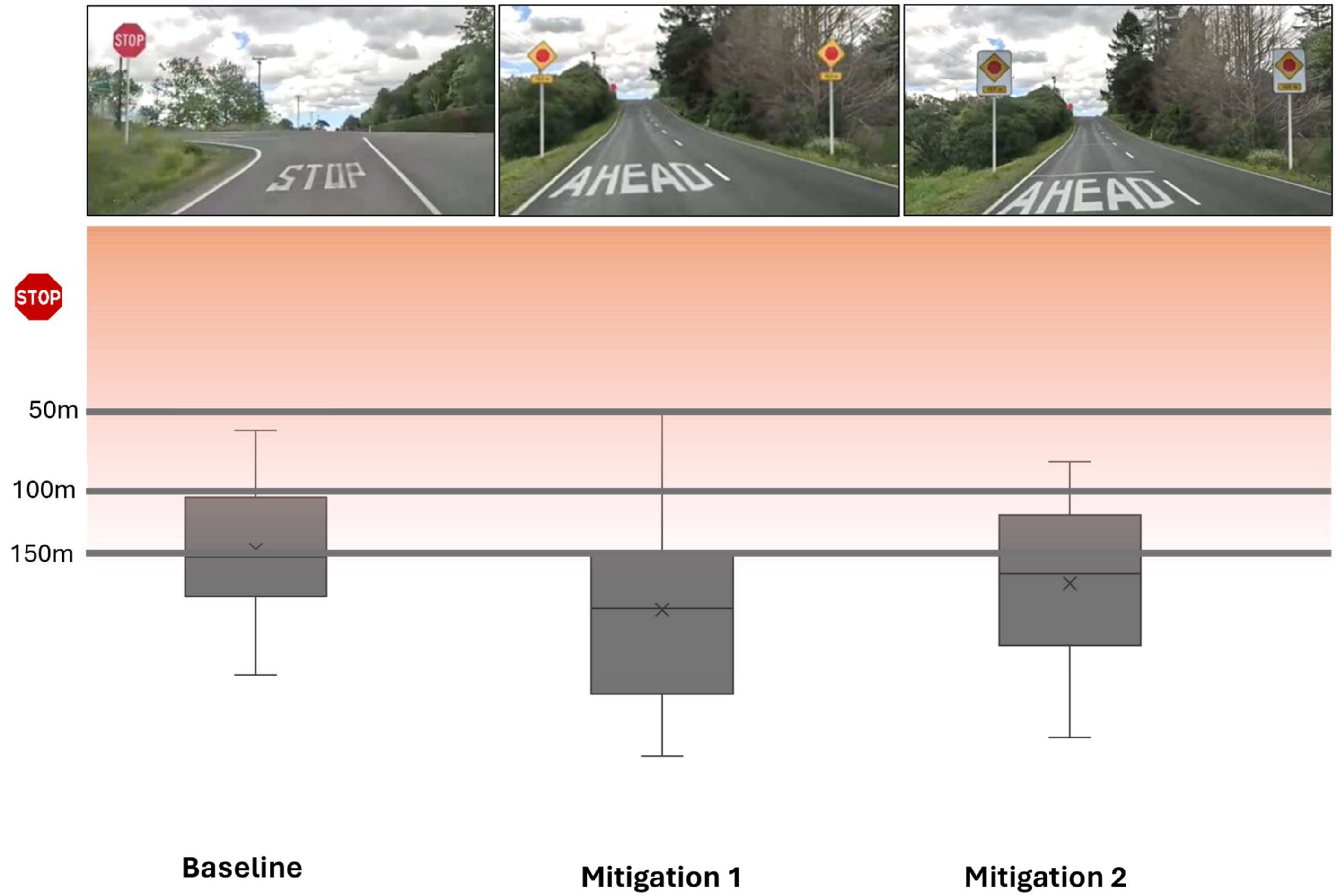

*Figure 20: box and whisker plot showing where (in distance) participants understood there was an intersection ahead at Tourist-Monument, with approximate distances from the intersection super imposed. X's show the median, and outliers are plotted. Note: actual measurements were in seconds from the intersection, however, the distances are shown to better contextualise the results.*

## 5.6. Participant feedback on interventions

Following their participation in the mitigation trial, participants completed questionnaire asking them about their views on each component of the trial mitigations (e.g. the oversize Stop signs). The questionnaire provided the team with an opportunity to better understand which aspects of the mitigations were most salient to participants. Participants were also asked to 'trade off' between interventions, indicating which they felt was the most impactful and why. This provides a useful indication of the acceptability to the public of the various potential crossroads mitigations.

The following section provides the results from the participant survey.

### *Summary of ratings of individual mitigation elements*

Table 4 provides a summary of participant ratings of individual elements of each mitigation trialled. Most of the design elements were rated positively by participants. Interestingly, some participants felt the white-backed Stop warning sign made it more difficult to identify the crossroad (compared to a standard sign). Based on participant comments, this is likely to be because it was unfamiliar.

*Table 4: Summary of participant ratings of the extent to which interventions helped them identify the crossroad.*

| Intervention | Participant ratings | | | | |
|---|---|---|---|---|---|
| | Much more easily | More easily | No difference | More difficult | Much more difficult |
| Larger Stop signs | 23 | 62 | 15 | 0 | 0 |
| Double Stop signs | 27 | 45 | 28 | 0 | 0 |
| Stop warning signs (both styles) | 52 | 38 | 10 | 0 | 0 |
| Stop warning (white backing when compared to standard warning sign) | 27 | 27 | 27 | 18 | 2 |
| Stop Ahead road markings | 60 | 33 | 7 | 0 | 0 |
| Transverse lines | 17 | 35 | 35 | 13 | 0 |
| Reflective markers | 9 | 30 | 60 | 2 | 0 |

*Participant ratings of oversize and gated Stop signs*

Participants rated the use of oversize stop signs positively with 85% indicating that the larger signs helped them identify the crossroad more easily. Typical comments included:

*'I could see them earlier with less ambiguity about what they were.'*

*'Since the sign is larger, you notice it earlier forcing you to focus on it when it becomes more easily visible.'*

Many participants (72%) also thought that the gated signs helped identify the crossroad. Although, some participants commented that they didn't notice the gated signs or found them confusing. Comments included:

*'Multiple signs in your field of view approaching intersection helped.*

*'Double Gated signs are more visible from further away, prompting the driver to slow down earlier. Double gated signs also suggest that it is a bigger and more dangerous intersection (even if it is not).'*

Participants were also asked to comment on where they thought that larger and/or gated Stop signs would be useful on New Zealand roads. A number of comments indicated that participants thought that having these signs on rural roads would be useful, particularly where cars are travelling quickly as they alert the driver to the need to slow down earlier. Interestingly, a few participants commented on driver factors identified during the crash review, indicating that they think the signs should be used in the following circumstances:

*'Semi-rural and rural crossroads, where it is quieter, and drivers are less likely to stop, and where drivers 'know the roads' as they are locals, as it encourages people to stop.'*

*'I think when you have been driving long stretches of flat roads as you zone out a bit to the road, the larger Stop signs will help.'*

*Participant ratings of Stop warning signs*

Ninety percent of participants indicated that Stop warning signs, in general, helped them identify the crossroad more easily. Comments suggested that they were highly visible, and alerted participants to the oncoming crossroad.

Interestingly, responses to the more novel warning sign with the white backing were mixed, with 54% indicating they made it easier to detect a crossroad when compared to standard warning signs. This also fits with the more variable key press response times to this intervention in the trial and suggests that some found the sign difficult to understand.

*'A large part of my identification of road signs is the shape, along with colour, image, and text. Having the white border masked that a bit, as I saw the rectangular overall shape, rather than the more distinctive ones, such as a stop or give way.'*

*'The stop signs with the white background I found confusing as to what it was because I am not used to seeing stop signs this way.'*

*'The one with the white backing was much easier to identify as the colours were distinctive and separated from the environmental background.'*

*'The white border sign was much easier to spot- especially when the sign is near a field (the yellow can become camouflaged) so the white makes it easier to see.'*

When asked what Stop warning sign they would prefer to see on New Zealand roads, the response again reflected the mixed opinion, 45% selected the standard Stop Warning sign and 55% selected the novel, white backed, sign.

### *Participant ratings of road markings and reflective markers*

Participants were asked about several road markings and reflective markers that were presented during the virtual simulation trial.

Most (93%) indicated that the Stop Ahead paint on the roadway helped them identify that they needed to stop or give way ahead. Comments included:

*'Sometimes it can be missed by drivers not scanning properly but still helps indicate that there is an intersection coming up.'*

*'I did notice these, and I prefer them to none. They are a great secondary thing to scanning for signs. Signs can be too high off the road and hard to see at times.'*

*'The stop ahead road markings give the first warning to reduce your speed and allowing the driver to reduce speed safely rather than at the stop sign or intersection.'*

When asked about transverse road markings, 35% of participants indicated that they didn't notice them during the trial suggesting that they are not as generally salient as other interventions. As might be expected in this case, only 52% indicated that they helped them identify that they needed to stop or give way ahead. Comments on the markings were mixed:

*'I thought that it was much easier to see that there was a stop sign coming up - very noticeable on the road and the length of the lines was good - showed something important was coming up that I needed to be aware of.'*

*'Didn't understand what these were and were offputting, needs to be advised to wider public if implemented in real life.'*

*'Not sure that these are a lot of help prefer the wording to STOP.'*

When asked if the transverse markings would be more effective as raised/rumble strips, 90% of participants said yes. This highlights a limitation of the study where audio-tactile responses from the transverse lines were not able to be easily added as a countermeasure.

*'If you make them slightly raised (like some hard shoulder markings) and successively closer the nearer you get to intersection (as used in the UK) you really feel like you need to slow down (as you hear and feel the rumble). The fact they are closer as you get nearer the intersection gives you the impression you are still going too fast and so slow down even more.'*

*'I think transverse lines with a slight bump would be helpful for drivers approaching a stop sign ahead as it's not just a visual warning but also a physical warning as you would feel the bump, driving.'*

When asked about reflective markers (presented in Mitigation 2), 55% of participants indicated that they didn't notice them during the trial. This may be because of the daytime conditions when reflectivity of the markers would not be as visible. Only 39% felt that they helped them identify the crossroad more easily. Generally, participants felt they would be more useful in a night-time situation. In the simulation it is possible that the raised reflective markers were less conspicuous than they would be in reality, as drivers are often highly responsive to subtle delineation changes.

### *Comparison/trade-off between intervention options*

When asked to select what they felt were the most important intervention options for rural crossroads in New Zealand, participants most frequently selected the following as their first or second most important option:

- Stop warning signs (either style) – 36 participants
- Double Stop signs – 26 participants
- Oversize Stop signs – 24 participants

# 6. DISCUSSION & RECOMMENDATIONS

This project was commissioned following several high-profile crashes at New Zealand crossroads that had raised concerns amongst road safety experts that some crashes may be caused by yielding drivers failing to detect the presence of the crossroad and therefore failing to stop or give way.

The goals of the work were twofold:

1. To better understand the frequency and causal factors of 'failure to detect' crashes at rural crossroads in New Zealand.
2. To identify and test effective, cost-efficient mitigations that road authorities could confidently roll out at scale.

The approach taken built on a substantial body of international research that both identified potential mitigations and provided evidence for the effectiveness of a proactive, risk-based approach to crash prevention where low-cost interventions are rolled out at sites where characteristics associated with severe crash types are identified.

In New Zealand, work identifying high-risk rural crossroads was recently undertaken (Harris & Blackmore, 2022). This provides NZ road controlling authorities with a head start in this approach. This project adds further confidence by providing a greater depth of knowledge on rural crossroad crashes and information about the likely effectiveness of 'failure to detect' mitigations.

## 6.1. Characteristics of crossroads crashes

'Failure to detect' crashes were found to occur at all rural intersection types in the CAS analysis undertaken for this this work. However, they were much more prevalent at rural crossroads, particularly those in the Canterbury region.

**Rural crossroads have a unique crash profile**

While some driver factors (particularly distraction, unfamiliarity, and speed) were identified as crash factors, the most consistent factors were related to the surrounding environment and road geometry.

'Failure to yield' crossroads crashes commonly occurred at sites with simple environments on minor or medium rural roads with long straights, little traffic, and few corners. Yeilding drivers had often had priority at earlier intersections.

**Environment and road geometry are major crash factors**

The crossroads where crashes had occurred were characterised by straight, flat yielding approaches that continued on straight after the crossroad. The priority road was often difficult to see and, in some cases, additional continuity such as hedges suggested that the road continued on ahead.

Comments by several participants during the trial support the idea that, for a driver, crossroads can be difficult to detect.

> *'It is so easy to miss Stop signs so anything to make them more visible is good.'*

> *'My observation through personal experience is that we need more signage on rural roads for intersections as sometimes they come out of nowhere.'*

> *'In Canterbury where I grew up, we have a lot of back roads with no signage or very minimal signage and it's really up to driver discretion and experience to know the big crossroads to stop/ slow down.'*

## Driver attentional issues play a role in crashes

Driver attention seems to be a factor in crossroads crashes. However, two different mechanisms appear to be in play.

In some crashes, the environment, such as long straights and low traffic volumes may have lulled drivers into a low attention state (autopilot or driving without awareness). With few cues in the environment to indicate the crossroad ahead, they may not have been 'snapped out' of their inattention in time to stop.

> *'During my trial, I didn't pass many other road users and I was alone on the road most of the time which can encourage distraction. For many kms, there is not much to see or take notice of besides grass/farm/hedges which I believe can mean drivers tend to pick up their phone or travel at a higher speed.'*

Conversely, in other crashes distraction and attentional narrowing may have been a factor. The SCU reports reviewed as part of this work, although a small sample, indicated that some drivers may have been unfamiliar with the area and focused on navigation (attention narrowed). Again, with few cues about the crossroad ahead, their attention may not have been drawn away from their task sufficiently to alert them to stop.

In both of these attentional states (driving without awareness and distraction) drivers can 'fail to see' important traffic information such as road signs (attentional blindness). These attentional errors may be why existing signage and markings hadn't worked in some of the crashes reviewed. It may not have been sufficiently obtrusive for a driver in a low-attention state.

## Interventions need to compensate for the lack of environmental cues of the upcoming crossroad

The results of analysis of 'failure to detect' crashes provides clear direction for the development of mitigations, suggesting they need to compensate for the lack of environmental cues, catch the drivers' attention, and 'snap' them into a more conscious proactive style of driving.

## 6.2. Mitigating 'failure to detect' crashes

**Focus: low-cost interventions that could be rolled out across the network**

Rather than focusing on novel interventions that may be high cost and difficult to implement, the mitigations selected for this project were intended to be efficient, practical, and cost-effective to roll out across the roading network, particularly in using existing TCDs as much as possible. Interventions were also recommended in a review previously undertaken for Waka Kotahi (Mackie, 2021).

**Current safety interventions at crossroads may not always be sufficient**

One of the key findings of the trial was that minimum standard mitigations for rural crossroads (a single Stop or Give Way sign at the intersection) may not be sufficient in some situations. A notable number of trial participants didn't identify the need to stop ahead at a crossroad until they were within 100m of the intersection (considered the danger zone in the trial). This is despite being cued to look for situations where they needed to stop or give way and being relatively alert, given they were taking part in a trial.

In real world situations, where drivers may be fatigued, or distracted, and/or crossroad signage may be difficult to see, such as in low light/cloudy conditions and against dark or complex backgrounds, there may be a real risk that the crossroad isn't detected by some drivers. In situations where environmental cues and road geometry are high risk (as evidenced by Phase 1 of this work), there is a very real need for additional safety interventions.

**Simple, well understood additional safety interventions may be best**

The mitigations tested in this trial were both successful. However, Mitigation 1 was more consistently effective. The unfamiliarity of Mitigation 2 seemed to cause issues for some participants. This suggests that existing, well understood, TCDs may be the best option at many rural crossroads, with enhanced features only being used when needed for specific purposes.

Additionally, it may not be the case that the more interventions elements you add, the more effective the mitigation is. A cheaper, simpler, more easily implemented and understood mitigation may be effective at most sites. Although, we acknowledge that backing boards are used when conspicuity is a problem and that may well still be warranted in these circumstances.

The components of the mitigations identified by participants as most salient/useful were the warning signs (either style) and the oversize gated Stop signs. This is consistent with the trial findings and suggests that any broadly rolled out mitigation should contain these elements. The oversize signs in particular, seem to be quite obtrusive and attention grabbing.

One element that couldn't be tested fully as part of the trial (We only tested these as visual elements as part of Mitigation 2) were audio-tactile transverse lines, although the team took the opportunity to ask about them in the participant survey. Participants felt that they would provide a good additional alert. This is supported by the Human Factors principle of utilising a range of senses such as sound and vibration. It may be that transverse rumble lines could be added at higher risk sites. Likewise, Stop Ahead signs with flashing beacons could also be adopted at these sites (once fully evaluated).

One factor to consider, when planning to roll out interventions across the network is the consequences at sites without treatments as risk may be increased there.

A roll-out programme should be as comprehensive and consistent as possible because having consistent and repeated cues is very important from a driver recognition and behaviour perspective. This further reinforces the need to prioritise simple and easily recognised TCDs at scale.

*‘These are good additions to give drivers an early indication of upcoming crossroads... In my experience, sometimes intermittent use of these extra controls can lull drivers into a false sense of security if they don't see them - sometimes drivers just need to drive slower to be safe on certain roads. ‘*

## 6.3. Mitigation costs

While it was beyond the scope of this project to complete a full cost analysis of mitigations, the team did take the opportunity to talk to road safety experts to get an early indication of likely (ballpark) costs to treat a crossroad site.

The road safety experts were asked to consider the cost of treating the site with:

- Overside gated Stop/Give Way signs
- Gated advance warning signs
- Transverse thermoplastic rumble lines in advance of crossroad
- Enhanced delineation (including RRPMs) leading to the intersection

The indications were that the cost to treat a site with these mitigations would be roughly $25-30,000 for a whole intersection. It was also noted that this cost would probably reduce significantly if a few local intersections were packaged. This figure does not include the maintenance of mitigations.

## 6.4. Next steps

The findings of this study, in combination with other New Zealand-based, and international, research should provide road controlling authorities with the confidence to develop a consistent and widespread low-cost treatment approach to mitigate ‘failure to detect’ crashes at rural crossroads, and roll this out with confidence.

Development of the treatment approach should include:

- Further interrogation of any crashes where mitigations already existed to refine the design. As noted within the report, the team made best efforts to understand what road marking and signage was on site at the time of each crash. However, in most cases Google Maps information had to be used which includes only very intermittent photos of a site. It was of interest that mitigations didn’t prevent some crashes and any patterns in circumstances whereby mitigations were less successful would be of interest. It may help identify sites where more intense mitigations are required (such as flashing Stop warning signs).

- Analyses of driver on-road behaviour at crossroads to confirm the findings of research in a real-world setting and extend our understanding beyond serious crashes, by better understanding situations such as near misses.
- Development of a treatment hierarchy based on risk. Other mitigations such as flashing beacons, transverse rumble lines, and any additional innovations should be evaluated via literature, and tested either in simulations or real-world settings, before being included in a treatment strategy.
- Where warranted, given the nature of crashes at the site, and risk profile, consideration and roll-out of Intersection Speed Zones and other priority road countermeasures could also be considered.

Any roll out should be comprehensively evaluated. We suggest on-road monitoring of key sites to further understand performance improvements in a real-world situation. However, this could happen in parallel with an initial roll out. Once further confidence is gained and crash reduction performance and cost-benefits ratios have been calculated, a nationwide roll out could be actioned.

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# 8. APPENDIX A: PARTICIPANT DEMOGRAPHICS

| Participant Characteristics | | Total (percentage) |
|---|---|---|
| **Participants** | Total | 60 (100%) |
| **Gender** | Male | 29 (48%) |
| | Female | 31 (52%) |
| **Age groups** | <30 | 25 (42%) |
| | 30-59 | 27 (45%) |
| | 60+ | 8 (13%) |
| **Frequency driving rurally** | Frequent (daily or weekly) | 37 (62%) |
| | Infrequent (monthly to 1-2 times a year) | 21 (35%) |
| | Never | 2 (3%) |
| **License Type** | Full NZ license | 34 (75%) |
| | Restricted NZ license | 10 (17%) |
| | Foreign License, legally allowed to drive in NZ | 5 (8%) |