November 19
World Day of Remembrance for Road Traffic Victims
http://worlddayofremembrance.org/

November 25-27
International seminar "Safe System Approach to Enhance Traffic Safety in Iran: Recent Activities and Future Directions"
Tehran, Iran
https://www.piarc.org/ressources/documents/INTERNATIONALS-SEMINARS-PROCEEDINGS/

December 24-25
ICTTP 2017: 19th International Conference on Traffic and Transportation Psychology
Dubai, UAE
https://www.waset.org/conference/2017/12/dubai/ICTTP

Erratum
There was an error in Figure 4 on p.54 in the print version of the article: Blackwell, R., Zanker, S. and Davidson, J. (2017). Understanding low level speeders to increase speed compliance via road safety campaigns. Journal of the Australasian College of Road Safety, 28(2), 47-55. The error has since been corrected in the PDF version that is available on http://acrs.org.au/publications/journals/current-and-back-issues/

Peer-reviewed Papers

Original Road Safety Research

The signs they are a-changin': Development and evaluation of New Zealand's rural intersection active warning system

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Key Findings

- RIAWS was developed and tested at ten rural high-risk intersections;
- The RIAWS was well received by the motoring public;
- VSL signs were effective at slowing motorists when a collision risk was present;
- The smallest 10% of chosen gaps by side-road traffic increased when RIAWS was active;
- Fatal and serious crashes reduced more at RIAWS sites compared with control sites.

Abstract

In New Zealand, high-risk rural intersections are an important area of focus for reducing deaths and serious injuries. Accordingly, the Rural Intersection Active Warning System (RIAWS) was developed to reduce traffic speed on major road intersection approaches when the potential for a collision exists. Electronic variable speed limit (VSL) or 'Slow Down' signs on the intersection approaches are triggered by the presence of side-road and right-turning traffic, and when traffic clears the signs turn off. This paper reports on an evaluation of ten RIAWS sites, some of which have been active for four years. We found that the RIAWS was effective in reducing traffic speed when potentially colliding vehicles were present. However, the 'Slow Down' sign was significantly less effective than a 60 or 70 km/h VSL, and was subsequently discontinued. In the three-year period since implementation, fatal and serious crashes have almost been eliminated at the ten RIAWS intersection sites. The active nature of the system increases driver state awareness, better prepares motorists for a possible event, and increases the gaps between potentially colliding vehicles. Generally, it seems that RIAWS has lasting, rather than short-term speed reducing effects, and this may underpin the emerging safety benefits. Overall, RIAWS is feasible, operates well, tangibly reduces travel speed when a crash risk is present, is perceived positively by the motoring public, and has shown tangible safety benefits.

Keywords

Rural intersection; warning; road safety; crash minimization; vehicle activated sign; variable speed limit

Glossary

DSI – deaths and serious injuries

ITS – intelligent transport systems

RIAWS – rural intersection active warning system

PET – post encroachment time

PTC – projected time to collision

VAS – vehicle activated sign

VSL – variable speed limit

Introduction

Background

In 2010, the New Zealand Government implemented the Safer Journeys Road Safety Strategy 2010-2020. The Strategy takes a 'Safe System' approach which emphasises, among other concepts that: the road environment needs to be more accommodating of human error; people are vulnerable to crash factors; and unsafe road user behaviour should be minimised (Ministry of Transport, 2010).

High-risk intersections are an important area of focus for Safer Journeys. Between 2008–2012, the five year period before the Rural Intersection Active Warning System (RIAWS) project commenced, intersection crashes accounted for 30% of all deaths and serious injuries (DSI) on New Zealand's roads (NZ Transport Agency, 2013, p.10). Furthermore, during the same time period, 17% of all DSIs on rural roads were at intersections (NZ Transport Agency, 2013). While only 5% of all DSIs happen at rural intersections, the social costs are likely to be proportionately higher because rural crashes are more likely to have higher threat to life serious injury crashes (Mackie et al., In Press).

A 'Safe System' response to high-risk intersections may include significant physical work such as a rural roundabout, often costing millions of dollars. While this approach should not be discouraged, a 'smart' system that responds to periods of actual crash potential (e.g. when intersecting vehicles are within proximity of each other) may be a cost-effective solution, especially for high-risk intersections that do not qualify for rural roundabout construction.

This paper describes a trial that was conducted at ten high-risk rural intersections across New Zealand from January 2013 until December 2016. The aims of the trial were twofold: 1) to compare the effectiveness of two electronic sign configurations at four high-risk rural intersections; 2) to analyse the effectiveness of a variable speed limit (VSL) sign at ten sites for up to a three-year period.

Our long-term goals are to improve the safety of New Zealand's high-risk rural intersections by significantly reducing the likelihood of crashes occurring, and to minimise the consequences of those crashes that do occur.

Review of Literature

Vehicle speed magnitude is highly related to crash risk and severity (Fildes & Lee, 1993; Nilsson, 2004; Richards & Cuerden, 2009; Wramborg, 2005), as is the distribution of speed (Aarts & van Schagen, 2006; Archer et al., 2008; Garber & Gadiraju, 1989). Therefore, an evidence-based approach to road safety would address speed, especially at higher risk locations. Accordingly, many countries are now focussing on speed management measures to improve road safety. In New Zealand, a project based on speed management to mitigate collision forces at high-risk rural intersections was initiated. The RIAWS development began with a scoping study (Mackie, 2010) to understand intersection Intelligent Transport Systems (ITS) based safety systems developed elsewhere.

The most compelling of the overseas examples was a trial by the Swedish Road Administration (SRA) between 2003 and 2007 of variable speed limit (VSL) signs placed at 19 locations. Many of the sites were located at intersections where the VSL was triggered by the presence of a side-road vehicle that may have the potential for a collision. At locations where a permanent 90km/h speed limit existed, a variable 70km/h speed limit was installed. At these sites, vehicle speeds reduced by 14km/h on average, accepted gap time increased by 1-2 seconds, and the system was perceived very positively by the motoring public (Lind, 2009). It is not clear whether these positive outcomes have translated into this solution being adopted more widely.

In 1998 in Virginia, USA a pilot Intersection Collision Warning System (ICWS) was installed to enhance driver awareness of the traffic situation at an intersection with a restricted sight distance and a 'Stop' control on the minor leg (Penney, 1999). In the five years prior to the ICWS installation there were 13 reported injury accidents (Hanscom 2001, cited in Tate, 2003). Following the installation there were statistically significant reductions in approach speeds (5%, mean) of vehicles on the main road of up to 5km/h, and an increased Projected Time to Collision (PTC) for the lowest 10% of PTC's (Penney, 1999). Similarly, a trial of active warning signs triggered by the presence of a vehicle at the intersection in Minnesota, USA resulted in speed reductions of 6.3km/h (Kwon & Ismail, 2014).

In Queensland, Australia, the Department of Transport and Main Roads have evaluated vehicle activated signs (VAS) on intersection approaches as part of a wider study of various VAS applications (Burbridge, Eveleigh, & Van Eysden, 2010). Preliminary results showed that mean and 85th percentile speeds reduced by 2-4km/h. However, the authors noted that the study's ability to assess speed reduction was limited by the presence of only one radar. In another Australian trial, VAS ('Slow Down') were installed at six intersections (Bradshaw, Bui, & Jurewicz, 2013). Although there were statistically significant speed reductions of 0.8 to 6.9km/h at four of the sites, there was an increase in mean speed of 0.5 to 3.4km/h at the remaining two sites. Bradshaw et al. (2013) identified that having two intersections with signs 300 meters apart may have reduced the effectiveness for the second sign, or that traffic completing a dog-leg manoeuvre between the two intersections may have confounded the data. The VAS signs used did not include speed limits which, like the slow down signs, are likely to be less effective than warning signs that incorporate a speed limit.

As part of a large-scale evaluation of VAS, Winnett and Wheeler (2002) studied the effects of vehicle-activated junction warning signs at four sites in the UK. The signs were activated by vehicle speeds on the major road approaches. At all sites, there was a large reduction in the proportion of vehicles travelling higher than the speed limit. Mean speeds fell, with the reductions ranging between 1.3 and 14.8km/h. Across the four sites the reduction in mean speed was 5.5km/h.

Reviews of VAS have consistently found that use of a speed limit in conjunction with a relevant warning or reason to slow down are most effective and that warning signs or speed limits alone are less credible and less effective (Baas et al., 2010; Nygårdhs & Helmers, 2007; Winnett et al., 2002). Therefore, it may be that a temporary, highly credible, and highly conspicuous change in speed limit is likely to be most effective at locations where a defined crash risk or road user vulnerability exists.

In New Zealand, VSLs have been widely used at urban schools during the morning and afternoon pick-up and drop-off times and have been successfully trialled at rural schools in higher speed environments (Mackie et al., 2013). However, VSLs, or any other VAS, have not been tested as part of a rural intersection safety system in New Zealand. There is therefore a need to more systematically and objectively evaluate the effectiveness of a VSL based intersection safety system, and this was the focus of the present study.

Method

This paper reports on a methodology in three parts:

- System development and site selection;
- Motorist behavioural and perceptual responses to RIAWS; and
- Cross-over evaluation.

System development and site selection

To ensure rigorous development of the RIAWS, a structured method was followed. Initially, the opinions of road safety experts were sought to develop the preliminary ideas. This was followed by a Delphi method, involving an iterative improvement process through an expert group. Finally, six focus groups with a total of 60 road safety experts were run to help refine the sign design.

Initially it was proposed that a full electronic sign should be designed specifically for the RIAWS. It was considered that, in addition to any instruction (speed limit or 'Slow Down'), there should be a clear and obvious explanatory message. This included giving an indication of the specific risk that was present (e.g. a symbol including a vehicle on a side road). However, as the design process progressed, it was determined that using existing sign designs would provide a more cost-effective, recognisable, and understandable system. Thus, the explanatory component of the sign system was static (based on the intersection's geometry), and was supplemented by the electronic instructional component of the system (see Figure 1).

Site selection criteria (Table 1) were determined to maximise the effectiveness of RIAWS and assist regional decision making, and Figure 2 shows the location of each site. For more detail about the individual sites, see an earlier technical report (Mackie, Scott, & Hawley, 2015).

Consistent with the site selection criteria, all of the sites had a history of injury crashes compatible with the objectives of RIAWS. Traffic volumes on the major road typically ranged between 5-10000 vehicles per day although one road had 15,000 vehicles per day. Traffic volumes on the minor road approaches ranged from 800-4,000 vehicles per day. All sites had 100km/h speed limits although a few had lower operating speeds due to curving approach geometry.

The RIAWS consists of the following elements:

- Side road high-definition radar sensors to detect approaching side road traffic approximately 150m from the intersection which then activate the main road electronic signs;

Figure 1. Examples of sign designs used in the RIAWS trial

- Side road limit line sensors (cut loops) to detect waiting traffic and trigger the end of sign activation following a delay;
- Right turn bay sensors (where right turn bays exist) 50-66m from limit line, to activate signs, plus limit line sensors to detect queuing traffic and terminate sign activation following a delay;
- VSL signs, or 'Slow Down' signs placed in each direction on the main road approximately 150m from the intersection;
- A central control system to manage the RIAWS and accommodate data collection equipment; and
- A Graphical User Interface (GUI) to remotely monitor the once-operational system in real-time.

Motorist behavioural and perceptual responses to RIAWS

A suite of measures was used to assess and evaluate the effectiveness of the 70km/h or 60km/h VSL on through-road vehicle speed. These measures were informed by previous

Figure 2. Map of RIAWS sites

studies (Charlton, 2003; Charlton & Baas, 2006; Lind, 2009; Tate, 2003; Yamanaka & Mitani, 2005) and are presented in Table 2.

All of these measures were carried out at all of the sites except for the perceptions survey and the gap analysis, which were only carried out at Himatangi due to project cost limitations.

Cross-over evaluation

Two cross-over studies using VSL and 'Slow Down' signs were undertaken in Northland (Puketona and Pakaraka), and in Canterbury (Kaiapoi and Burnham). Each sign was trialled at the same site over different time periods, with the alternative sign being trialled at a nearby similar site at the same time. The study design ensured that any order and

Table 1. RIAWS site selection criteria

1.	Use High-Risk Intersection Guide (HRIG) identification procedures (NZ Transport Agency, 2013)
2.	Evidence of crash codes compatible with objectives of RIAWS, as per Montella (2010).
3.	Preferably higher volume major road, with side-road traffic volume lower
4.	Existing 100km/h major road speed limit
5.	Possible intersection approach visibility issues
6.	Relatively simple geometry (T or X)
7.	No planned works in short-to-medium term. Longer-term may be OK as RIAWS may provide an interim solution (e.g. before a rural roundabout)

Table 2. Measures used to evaluate the effectiveness of RIAWS

Measure	Method	Description
Visual observation of RIAWS	Direct observation by regional road safety engineer and project team at 'go live' day.	To determine that the RIAWS system was working correctly (by an independent person), as well as a safety check to ensure no obvious adverse effects were caused by the RIAWS.
Sign performance and utilisation	Logging of sign activation information from system.	To determine the proportion of time the signs were on or off. This was important for the system's usability, motorists' perceptions of the signs' credibility, and estimations for power demand.
Point Speed of major road vehicles	Cut loops at the intersection on the through-traffic lane (both directions).	Baseline: '*sign would be on*' represented a potential collision risk condition where another vehicle was present at the intersection. '*sign would be off*' represented the condition when no other vehicle was present at the intersection. Follow-up: 'Sign-on' when VSL is activated 'Sign-off' when VSL is inactive Target: to gather 14 days of data in three sets; prior to RIAWS installation, one month following, and six months to one year following.
Vehicle counts	Cut loops at the intersection on the through-traffic lane (both directions).	Number of vehicles for conditions outlined above
Motorist perceptions of RIAWS	Automatic number plate (ANPR) collection of motorists (Himatangi site only).	Using these data, an invitation was sent to the vehicle owner inviting them to participate in a survey.
Minor road vehicle gap selection (i.e. Post encroachment time – PET).	Camera mounted to lighting pole with remote operation. Time analysis from video positioned at intersection (Himatangi site only).	PET = the time difference between when a vehicle leaves a defined area within the intersection and when a potentially colliding vehicle enters the same defined area.
Crash data	Crash data were collected from each of the sites using the Crash Analysis System (CAS).	Fatal, serious, injury, and non-injury crashes were measured for the five-year period prior to RIAWS installation, and up to four years following. To account for the different time periods, a common unit of crashes per month was calculated for each site and then all ten sites were combined for the overall analysis. RIAWS crash performance was compared with ten control sites of similar high-risk nature.

location effects were cancelled out, leaving the effects of the sign as the key determinant of traffic speed.

Results

Speed data summary statistics were calculated for each site. Speed data were often not normally distributed, therefore modal speed is presented in this paper. Effect sizes using Cohen's d (Cohen, 1992) were calculated for changes in mean speeds, which was considered more appropriate than a statistical comparison of means (such as a t-test), as a magnitude of change, rather than evidence of difference in means.. To demonstrate this, for the Himatangi site, statistical significance would be reached when the t-statistic reaches 1.64 (one tailed) or 1.96 (two tailed). The analysis shows that the t-statistic was 64.91 and the p-value =0.000. With such large sample sizes (e.g. 20,000-50,000 vehicle movements across 1-2 weeks in each direction), statistical significance is easily reached.

System Performance

The first ten RIAWS systems operating around New Zealand were included in the trial and they have experienced no major sign faults reported since installation. The longest operating site (Himatangi, Figure 3) has been working effectively for four years. Activation and speed data is emailed from each site daily. Most intersections had relatively high activation rates (% time with electronic sign on) during busier times (average hourly maximum 76% across the trial), with an overall average activation rate of 40% across the trial. Typically, the signs were infrequently activated at night time. During weekends, the overall average activation rate was 35%.

Figure 3. The RIAWS in operation at Himatangi (side-road vehicle is shown in the circle)

Motorist perceptions of RIAWS

Motorist perceptions of the 70km/h VSL at the Himatangi site were collected. In total, 307 motorists responded (297 posted paper, 10 online), representing a 31% response rate. Of those respondents, 68% had encountered the illuminated signs at the intersection.

Overall, motorists' responses were positive, demonstrated not only by the latent understanding of the sign, but also the high percentage of respondents (81%) who felt the VSL would lead to a safer intersection. Most respondents correctly understood the key message from the RIAWS, with only 14% disagreeing or strongly disagreeing that the signs were easy to understand. Likewise, only 25% of respondents disagreed or strongly disagreed that the signs sent the right message. A small proportion of respondents (8%) expressed concern that drivers might ignore the sign.

Motorist behavioural responses to RIAWS

Since installation over the medium to long-term, RIAWS was effective in maintaining lower traffic speeds (near the target speed of 70km/h) at almost all locations. Example speed distributions for the original Himatangi site are shown in Figure 4 below.

Results from one of the two cross-over studies, presented in Figure 5 clearly show that the 70km/h VSL signs resulted in greater speed reductions compared with the 'Slow Down' signs. At the sites where a 'Slow Down' sign was installed after a VSL sign, there were lower speeds than when the 'Slow Down' sign was the first sign installed. This may indicate some residual level of effect from the previous VSL sign.

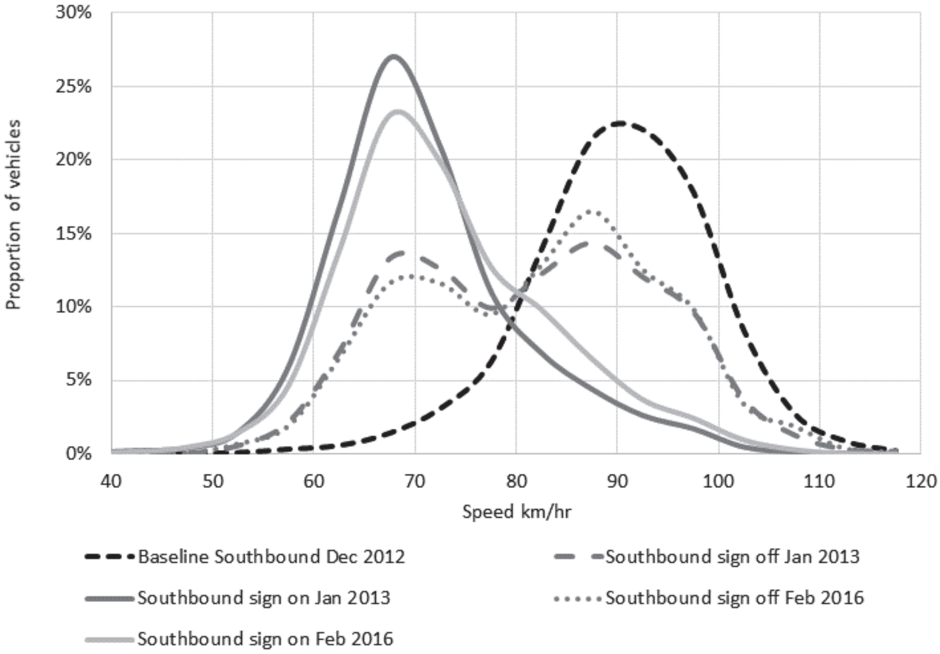

Figure 4. Speed distributions at the Himatangi site from 2012-2016

In cases where 'Slow Down' signs were installed, through-traffic speeds reduced in most cases, but to a much lesser extent compared with those sites where the VSL were installed. It was determined that the speed adjustment made at the 'Slow Down' sign was insufficient to minimise injury. Indeed, from our modelling, crashes under a 'Slow Down' sign would still result in severe injury. Following these findings, 'Slow Down' signs were replaced with 70km/h signs, and in one case (Pakaraka) 60km/h signs, remained at the sites after the trial.

Evaluation of 60km/h VSL Sign

At the Pakaraka site, a 60km/h VSL sign was trialled following the conclusion of the cross-over trial (Figure 6). Although the 60km/h signs were more effective than the 70km/h signs, compliance with the 60km/h sign was lower (vehicles slowed to 5-7km/h above the limit under the 70km/h condition, and under the 60km/h condition, slowed to 11-12km above the limit). Note that mean speeds are used for this analysis as the modal data was difficult to interpret

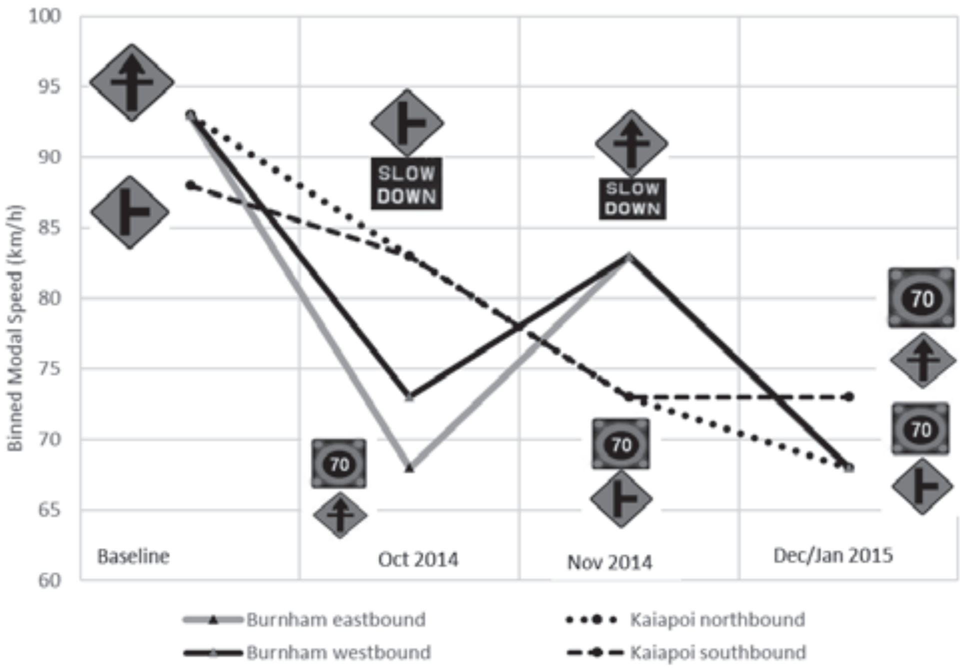

Figure 5. Canterbury cross-over study of modal speed and sign type: Kaiapoi and Burnham

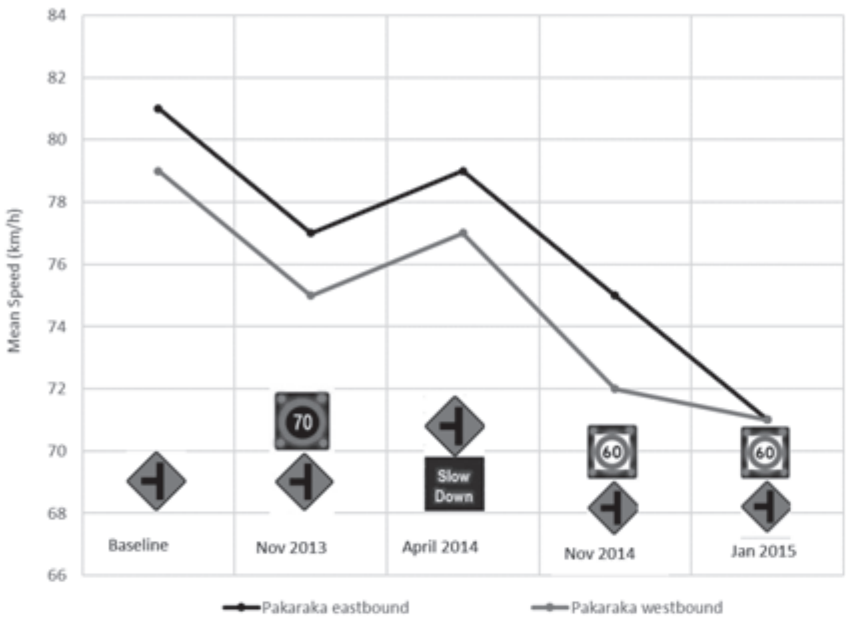

Figure 6. Sign comparison (mean speed) at Pakaraka

for some of the data sets. This performance was confirmed at a more recent RIAWS site (not included in the trial) which utilises 60km/h signs, where modal speeds have dropped to around 73km/h following travel speeds of 90km/h.

Speed Results across 70km/h RIAWS sites

Following RIAWS implementation, significant reductions in modal speeds (68-76km/h) were seen, compared to the baseline 'collision risk' condition (80-95km/h) (see Figure 7). Mean speeds also reduced significantly, but to a slightly lesser extent. Overall, these speed reductions when RIAWS is active have generally been maintained over time.

The immediate post-implementation effect sizes were medium to large for the 70km/h signs (ranging from 0.4 to 2.3) and small to medium for the 'Slow Down' signs (ranging from 0 to 0.47). For the 70km/h signs, in locations with long straights and good visibility (Himatangi, Yaldhurst, Newbury, Kaiapoi, Burnham, and Longlands) effect sizes were larger, reflecting the greater speed reductions by through-traffic at these locations. In comparison, at sites with nearby corners and less visibility (Pakaraka, Puketona), where baseline speeds were already suppressed, the effect sizes were smaller.

For sites with available medium-term data for the 70km/h VSL sign, effect sizes remained relatively stable 10 to 16 months on. This mostly remains true for the sites with longer-term data.

Gap Selection

A preliminary evaluation of minor road vehicle gap selection (PET) was carried out at the Himatangi site. An increase in the mean value of the smallest 10% of recorded gaps was measured when RIAWS was active, indicating a potential safety benefit. At the very least there was no worsening of motorist gap choices. However, it is unclear if side-road motorists chose larger gaps, or whether major road vehicles simply took longer to reach the intersections due to their lower travelling speed.

Crash and casualty outcomes

The crash data before and after the installation of RIAWS across the ten sites, along with similar data for ten control sites, is shown below in Table 3, along with the overall number of months available for analysis. The table represents crashes at the ten trial RIAWS sites located within a 50m radius around each intersection. The reported crashes were identified from the CAS system 600 months (60 months of data multiplied by ten sites) before, and 284 months (sum of months since installation over 10 sites) following RIAWS installation until 31st December 2016.

The crash rate and severity of injuries reduced significantly at the sites where RIAWS operated for up to four years. Indeed, traffic crash records suggest that RIAWS mitigated the severity of the few crashes that occurred. These early suggestions of tangible road safety effects are consistent with the positive outcomes found through the other surrogate safety measures used in the evaluation.

In the crashes across all RIAWS sites since installation, the reported speeds were between 70 and 80km/h. In at least four of the post-implementation crashes the drivers were overseas tourists often driving rental cars.

Since installation, fatal and serious crashes related to the RIAWS were eliminated. However, one fatal crash (resulting

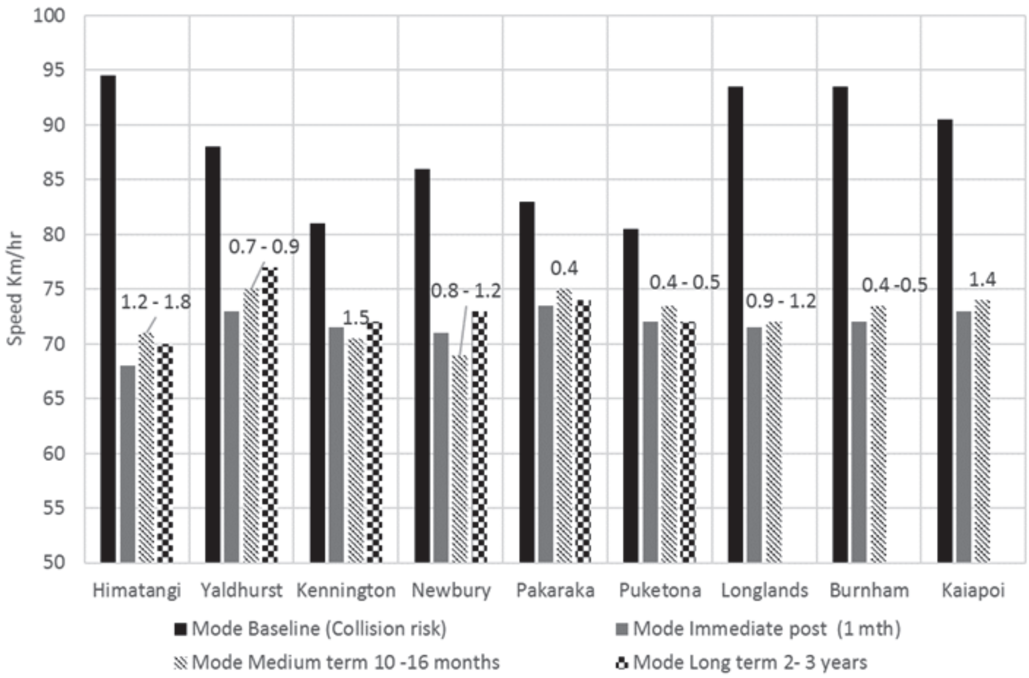

Figure 7. Modal traffic speed for each RIAWS site (both directions) for 'collision risk' situations

from fatigue); and one serious injury crash (a motorcycle hit from behind at low speed on the side road) occurred within a 50m radius of two RIAWS sites. It was established that RIAWS would not have made a difference to the outcome of those crashes. In the 50m radius around the RIAWS sites, the fatal and serious crash rate reduced by 79% from 0.35 crashes per month to 0.02 crashes per month. The overall crash rate reduced by 51% from 3.23 crashes per month to 0.92 crashes per month.

Note that these crash statistics include all crash types and so it is inevitable that some crashes will be included in the before and after statistics that the RIAWS cannot hope to influence. However, it is important to understand the intersection's overall safety performance to comprehend the influence that RIAWS is likely to have. Given the large fatal and serious casualty reduction effect, RIAWS is clearly well designed for the major risks that exist at high-risk rural intersections.

Discussion

RIAWS effectiveness

The findings suggest that RIAWS is well accepted by the motoring public, improves motorist gap judgement (accepting longer gaps), reduces through-traffic speeds to safer levels when potential conflict situations exist, and reduces high severity crashes (and crashes in general) at high-risk rural intersections.

The speed outcomes are compelling, much more so than many other road safety countermeasures. In most situations, compliance with the 70km/h VSL was maintained and there are no examples of tangibly diminished compliance over time. Compliance with the 60km/h speed limit examples appear to be lower, despite lowering travel speeds through the intersection more than for the 70km/h signs. In addition, the VSL sign was more effective than an instructional sign alerting motorists to a potential hazard (i.e. 'Slow Down'), which is supported by related trials from Victoria, Australia (Bradshaw et al., 2013). The longer-term findings reinforce that the RIAWS is most effective on relatively simple and high-speed intersections where motorists have time to react to the system and adjust their behaviour.

The reasons for the success of RIAWS is of interest as it may yield clues for other speed limit and electronic sign applications. A key reason could be the credibility of the system, providing reasonable instructional information to support motorists' existing perceptions of risk. This is consistent with other recent research evaluating the effectiveness of 20km/h speed limit signs on buses (Baas et al., 2014), and VSL trials at rural schools (Mackie & Scott, 2014). Across these studies, it was suggested that the VSL signs are effective because they are used in 'high credibility' locations, are attention-grabbing, noticed well in advance, and provide a clear and legal instruction to motorists with supplementary information about why motorists are being asked to slow down. For the RIAWS study, baseline speed data for the 'sign would be on' condition shows that even with no intervention there is some tendency for motorists to make a minor adjustment and decrease their speed when side-road vehicles are present, suggesting that the sign would therefore seem credible to motorists, and in fact may be helpful by providing overt instruction about the behaviours that are needed to stay safe (e.g. travel at 70km/h).

Although more time is needed to confirm the safety performance of RIAWS, the positive safety benefits experienced to date are likely to be a result of the high levels of compliance with the VSL. Modelling carried out as part of the development of RIAWS suggested that approach speeds of 80km/h, are likely to avoid serious or fatal injuries most of the time, and approach speeds of 60km/h are likely to result in serious or fatal injuries on very few occasions. The findings of the pre/post analysis show that intersection travel speeds of around 70km/h (and presumably lower collision speeds) are likely to be associated with a transformational reduction in fatal and serious casualties due to increased driver state awareness, increased availability of reaction time, and significantly reduced crash forces. Individual examples of crashes at RIAWS intersections have added support to the evidence for their safety performance. Indeed, the few crash records reported with RIAWS operational

Table 3: Post-RIAWS crash history across ten trial sites and ten control sites

		Pre RIAWS Crashes per month	Post RIAWS Crashes per month	% Reduction	Net Reduction
Ten RIAWS Sites (600 months pre, 284 months post)	Fatal and serious	0.35	0.02	-93%	-79%
	Minor injury	1.40	0.26	-81%	-49%
	Non-Injury	1.48	0.64	-57%	-48%
	All crashes	3.23	0.92	-71%	-51%
Ten Control Sites (600 months pre, 300 months post)	Fatal and serious	0.35	0.30	-14%	
	Minor injury	1.28	0.87	-32%	
	Non-Injury	1.13	1.03	-9%	
	All crashes	2.77	2.20	-20%	

indicate approach speeds between 70 and 80km/h and drivers seeing and reacting to the VSL signs. This reinforces that that some crashes may have been more severe if the RIAWS were not in place.

Design considerations for RIAWS

Since the original RIAWS installations, improvements and modifications were suggested, and in some cases implemented. For example, a pulsing roundel (by flashing the inner or outer LED rings while leaving neighbouring rings illuminated) instead of separate flashing lights was a recent change to the sign design. This appears to be effective and is likely to be utilised in the future.

The most successful RIAWS applications were on long, straight roads where motorists have plenty of time to react to the active VSL. For curving roads with approaches with limited visibility, it may be that supplementary advanced signage is needed to prepare motorists for a potentially changed speed limit ahead. However, this has not been a large problem to date.

While VSL signs are effective in capturing drivers' attention, their presence may influence the recognition of existing nearby signs (Rama, Luoma, & Harjula, 1998). This was raised when comparing the relative effectiveness of the VSL sign and the supplementary intersection sign immediately below. The VSL sign, with its moving elements, grabbed attention and the supplementary sign could potentially be overlooked. However there have been no reports of credibility issues associated with the system.

Operational limitations of RIAWS

RIAWS isn't considered a 'Safe System' treatment at high-risk rural intersections. Rural roundabouts are considered a 'Safe System' treatment due to their inherent safety and ability to accommodate many types of errors. It could be argued that a RIAWS does not accommodate motorists who deliberately violate the speed limit or somehow do not respond to it, and therefore expose intersecting vehicles to potentially fatal side impact crash forces. The intention with RIAWS was to at least reduce the impact speeds to potentially 50-60km/h on impact. Crash examples have shown this performance has been exceeded, which may account for the high safety performance. Furthermore, the safety performance of RIAWS to date is close to the performance that has been reported for rural roundabouts (Newstead & Corben, 2001; NZ Transport Agency, 2013).

However, RIAWS is significantly more cost effective than a rural roundabout. A challenge may therefore occur where a RIAWS is used as an interim measure pending a rural roundabout. If the RIAWS performs to a high level, as demonstrated in this trial, then the business case for a rural roundabout may be poor and it may not proceed. Conversely, a greater number of high-risk intersections may be treated using RIAWS than if rural roundabouts alone are considered and so potentially the network wide safety performance of RIAWS might exceed that of a rural roundabout for a given level of investment.

Study limitations

Although the RIAWS evaluation was relatively comprehensive and the performance of RIAWS was clearly very positive, a longer period to measure the safety performance at the various RIAWS sites is desirable to give more confidence to these findings.

This trial focused on the high-risk intersections targeted by selection criteria (Table 1). Although a variety of intersection types have had RIAWS installed, the trial intersections were deliberately chosen for their relatively simple attributes, with few complicating features such as multilane roads, complex geometry, or existing engineering features. It is not yet certain whether RIAWS would be equally as effective at more complex intersections and next steps could consider these intersection types.

Future work, implications for further use

The evidence given in this paper supports further use of RIAWS to mitigate risk at high-risk rural intersections. The ultimate success of RIAWS - a reduction in DSIs, will be measured over a five-year period to determine the safety performance at each intersection. Apart from preliminary measures of gap acceptance by side-road motorists, the trials have not focussed on the role of side-road or right-turning vehicles in potential intersection crash situations. Further work to understand the mechanisms of intersection crashes or the effectiveness of various intersection safety countermeasures, may consider the situational awareness and behaviour of side-road vehicles. Additionally, future research could examine the effectiveness of different variable message sign warning systems as part of RIAWS, such as weather events (e.g. fog, ice, wind, wet and slippery), or blocked lanes (e.g. crash, tree branch, truck spill).

Conclusion

The trial of RIAWS at ten intersections around New Zealand showed positive results and the trial objectives were achieved. RIAWS is feasible, operates well, is effective, is perceived positively by the motoring public, and has shown tangible safety benefits consistent with the 'Safe System' approach. All ten RIAWS trial sites remain in service and additional RIAWS sites have been implemented.

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