The Safety Effectiveness of Electronic Curve Warning Signs

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ABSTRACT

Over the period 2008 to 2011, the NZ Transport Agency (NZTA) installed 37 electronic curve warning signs (ECWS) at the beginning of some of the state highway's highest risk curves in order to warn approaching drivers when their speed exceeded a threshold and to reduce the number of crashes and the severity of those crashes.

The main objectives for the research was to evaluate the effect of ECWS on reducing the risk of a crash, especially high severity crashes, as well as their effect on speed.

Data collected included three years' worth of crash numbers and severity, before and after installation of the ECWS, along with before-and-after vehicle speeds where these were undertaken (not all sites). Each ECWS site was matched with a control site to take into account the regression to the mean effect. Crash data was extracted from the CAS database for both ECWS and control sites.

Key findings include a 36% reduction in all crashes at ECWS sites and an 80% reduction in death and serious injury crashes. Mean and 85th percentile speeds were found to reduce on average by 4.3km/h.

INTRODUCTION

"Out of context curves" are defined as curves with a radius less than 400m on state highway rural roads. They are high risk locations that are subject to a high number of death and serious injury (DSI) crashes. There are over 17,000 out of context curves on the New Zealand state highway network (New Zealand Transport Agency, 2015a). Between them they have had about 2,500 DSI crashes in the five years between 2009 to 2013 inclusive. In the same period they had close to 22,000 crashes altogether, including 5,800 minor injury crashes.

New Zealand's current road safety vision is "a safe road system increasingly free of death and serious injuries" (Ministry of Transport, 2010).

The main purpose of this paper is to examine the effectiveness of electronic curve warning signs (ECWS) in reducing crash numbers, crash severity and vehicle speeds on the New Zealand state highway network. A particular focus is on DSI crashes.

BACKGROUND

New Zealand's current road safety strategy—Safer Journeys 2020—is based on taking the "safe system" approach. It acknowledges that while we cannot prevent crashes occurring, we can reduce DSI crashes in four key ways – through safe users, safe vehicles, safe roads and roadsides, and safe speeds.

Analysis of New Zealand crash data indicates that single-vehicle run-off-road crashes is the most common type of crash on rural roads (New Zealand Transport Agency, 2015b), and account for 54% of high severity crashes on New Zealand's rural roads (New Zealand Transport Agency, 2012).

Recently, ECWS have been installed at a number of out of context curves on the New Zealand state highway network that have high severity run-off-road crashes. They have also been installed on those curves with significant injury and non-injury run-off-road crashes, while a few have been installed on curves with no crash history. The signs alert drivers to a high risk environment, and encourage them to reduce their speed in accordance with the advisory speed and so negotiate the curves successfully. All of the curves had signs in advance warning of the curve ahead. Most of them also had advisory curve speed signs in advance. Other safety improvements at these sites include regular maintenance of the surfaces, and improved signage and markings.

ECWS contain a speed-activated radar. The signs flash a warning when you approach a curve in excess of the advisory speed. There is no electronic display when vehicles are travelling at or below the advisory speed of the curve. When vehicles are travelling up to 10 km/h above the advisory speed, the sign illuminates a large curved arrow indicating the upcoming curve. At more than 10 km/h above the advisory speed, the sign illuminates both the curved arrow and a "Slow Down" message.

An ECWS is shown below in Figure 1.

Figure 1: Example of electronic curve warning sign in action (on SH1 Desert Road)

There have been a total of 43 ECWS installed throughout the country (up to the end of 2015), with the Waikato region containing more than half of these (23). The Bay of Plenty region has six, as does the Marlborough region; while the Auckland and Wellington regions have three each and Southland has two. The signs are located on a mix of speed limits between 50 km/h and 100 km/h.

In the past 18 months, four ECWS have been removed as the curves they were located on have been realigned, while one ECWS has been removed due to an intersection on a curve being upgraded to a roundabout. One other ECWS was removed due to malfunction and has not been replaced to date.

LITERATURE REVIEW

A literature review was undertaken as part of this research. The purpose of this literature review was to examine prior research findings relating to ECWS systems and to assess the use of ECWS in reducing high severity crashes and vehicle speeds.

The literature reviewed that was directly relevant to this project is summarised below.

A paper was presented at the 2010 Institute of Professional Engineers New Zealand Transportation Group conference (Kortegast and Gardner, 2010) that included information and data on the trial installation of two ECWS in Marlborough. This paper was one of the first in New Zealand to evaluate ECWS. The two ECWS were installed at the site of a high risk curve, about 3km south of Blenheim on State Highway 1. The curve first had the speed limit reduced from 80 km/h to 70 km/h and a guardrail installed to protect houses that had been hit by vehicles in previous crashes. The improvements were completed in May 2009, and the ECWS were installed in June 2009 in both directions.

At the time of the presentation in 2010, there had been no recorded crashes after installation, with ten crashes recorded before installation, while before-and-after speed surveys indicated that there had been a 5 km/h reduction in mean vehicle speeds ("before" speeds were measured after the implementation of the reduced speed limit). The Kortegast and Gardner paper highlighted that as the signs had only been operational for approximately eight months, further monitoring and data collection would need to be carried out. The ECWS were removed in 2014 as the curve was realigned. A search of the NZTA crash analysis system database (New Zealand Transport Agency, 2015b) resulted in no recorded DSI crashes in the five years from the installation of the sign until its removal. There was one recorded non-injury crash, although this crash was intersection related. A total of ten crashes (four minor injury and six non-injury crashes) were recorded in the three years before the installation of the sign, indicating a large decrease in crash numbers associated with the installation of the ECWS.

One of the most relevant pieces of research looked at the safety effects of dynamic curve warning signs at rural horizontal curves in Iowa (Pike, et al., 2013). The warning signs had subtle differences to New Zealand ECWS. When it detects vehicles approaching a curve above a predetermined speed, the Iowa system activates flashing light emitting diodes (LEDs) in the curve warning sign, and then into the chevrons, to alert the driver to the upcoming curve. The Iowa research is part of a national project in the USA, called the 'Sequential Dynamic Curve Warning System'. It involves the Texas Transportation Institute (TTI) working with the Centre of Transportation Research Engineering (CTRE) in Iowa. CTRE are evaluating eight new sites within three states, while TTI have four new sites and four existing sites (with eight comparison sites).

The CTRE report (Smadi, et al., 2014) tested and evaluated the effectiveness of dynamic curve warning systems in reducing vehicle speed and the frequency and severity of speed-related crashes on horizontal curves on rural roadways. The full analysis looked at 12 sites and 24 control sites. The results indicated vehicle speed reductions of 0 to 4.8 km/h (85^{th} percentile) and 1.1 to 4.5 km/h (mean), one month after installation. After 12 months, speed reductions were similar, at 0 to 4.8 km/h (85^{th} percentile) and 0.3 to 3.5 km/h (mean). After one year, crash reductions were positive, but not enough time had passed for these results to be statistically significant.

A research project in Minnesota evaluated the speed impacts of dynamic curve warning signs at three rural locations with low traffic volumes (Robinson & Knapp, 2012). The research supplemented and expanded on the national project for a Dynamic Speed Feedback Signs (DSFS) demonstration study. Signs were installed at three sites in May 2010. Speed data was collected at each site, just before the curve and within the curve, for one week before and one month after installation, and also at six months, one year, and 18 months after installation. Control site locations were selected and analysed, and similar before-and-after speed data collected. The results, averaged across the time periods and sites, indicated an overall reduction in speed of between 3 km/h and 11.2 km/h. At six months after installation, the average speed reduction was 4.8 km/h. The report concluded that, due to the limited number of sites, the research and findings should be considered in context of a national study. However, it noted that sometimes it may not be appropriate to aggregate results across states as the road environment could vary.

A dynamic curve warning sign was deployed at one site in Oregon (Bertini, et al., 2006). The system directed messages on a dynamic message sign to drivers based on the observed speed of approaching vehicles. Vehicle speeds were measured over seven days, four before and three after installation of the sign. A quantitative evaluation of the system indicated that the signs were effective in reducing the mean speeds by approximately 4.8 km/h (southbound) and 3.2 km/h (northbound). These results were statistically significant at the 95 percent confidence level. The distribution of speeds shifted to the left after installation of the signs, and the speed differences were found to be statistically significant with a lower number of vehicles in the higher speed bins. There were no “after” crash records as the system was new.

The Austroads (2014) report, “*Methods for reducing speeds on rural roads”,* indicated a 35% crash reduction for vehicle activated signs at rural curves and a 6 km/h speed reduction (Austroads 2014, Appendix A1.4).

A major study of the effects of vehicle activated signs was carried out in the United Kingdom (Winnett & Wheeler, 2002). It included 19 sites with speed limit reminder applications, but only three intersection sites and two curve sites. Speed surveys were carried out before and after installation and the Empirical Bayes method was used to analyse crash data. At the two curve sites, personal injury crashes reduced by 78% and speed reduced by around 7 km/h.

Research is emerging in relation to the effectiveness of ECWS systems (Robinson and Knapp, 2012; Pike, et al., 2013). There seems to be some correlation between the results of the research, with a 5 to 6 km/h reduction in speed and a 30-35% reduction in crashes from most of their studies. In some studies, it is difficult to assess the levels of significance of the findings due to small sample size or mixed methods (Kortegast & Gardner, 2010; Bertini, et al., 2006). However, taken together, they show a consistent trend which might be expected to be reflected in the New Zealand data.

Future research studies on ECWS would benefit from before-and-after data for multiple sites. The use of similar methodology across countries would enable global comparisons of the effectiveness of ECWS.

METHOD OF ANALYSIS

Before-and-after evaluations typically involve the comparison of a “‘treatment group” and a “control group”. The treatment group has countermeasures implemented, whereas the control group does not. Relevant data (in this instance, vehicle speeds and/or the number of crashes) are taken before and after implementation, for the same time period, for both the treatment group and the control group.

For this paper, crash data was considered for the three years before and the three years after installation of ECWS. Five years may give a more consistent representation of the long-term risk at locations but it is often important to assess the impact before that length of time has passed and many of the installations have not been in for five years.

Only those ECWS located on rural roads with speed limits 80 km/h and above were used for the crash and speed analysis, as the ECWS located on lower speed roads did not typically have DSI crashes.

A total of 27 ECWS sites were used for the crash analysis. Each ECWS site was matched with an appropriate control site in order to compare before-and-after crash numbers and severity.

The control sites have similar type curves to their corresponding ECWS sites, with similar approach and departure speeds, and comparable curve radii and curve lengths. They are preferably located in the same geographical area, but this was not always possible due to the nature of curves in New Zealand.

The control sites take account of the systematic changes in the environment affecting the underlying true crash rate of the treated site. The control sites also take account of the regression-to-the-mean effect as much as possible.

The control sites were selected from the out of context curve list as provided by the NZ Transport Agency's national office. This list is large and contains details of the entire out of context curves on the state highway network.

The details of each ECWS site were matched to find similar sites based on the following criteria:

Match 1: Direction of curve same as ECWS site
Match 2: Curve radius within 5m of the ECWS site
Match 3: Curve length within 20m of ECWS site
Match 4: Curve entry speed within 5 km/h of ECWS site (with same speed limit)
Match 5: Curve speed within 5 km/h of ECWS site (with same speed limit)

This method resulted in a match for each ECWS site with approximately 30 potential control sites. These sites were then matched more closely to select those with similar approach and departure gradients to their corresponding ECWS site, resulting in about 3 closer matches per ECWS. Finally, annual average daily traffic (AADT) volumes were compared, and the closest match for each ECWS site was selected as its control site.

For the crash analysis and comparison, crash data for the one, two, and three year periods before-and-after installation was extracted for each ECWS and control site. Crashes have been assessed in terms of overall crashes, minor injury crashes, and DSI crashes. Crash data for one and two years before and after installation of the ECWS has been assessed in order to identify any novelty effect – whether the signs may evoke a driver response, such as greater caution, immediately after installation, that the driver subsequently considers excessive and reduces their speed accordingly.

Crash Data

Road crashes in New Zealand are recorded in a Crash Analysis System (CAS). The CAS is a computer system that provides tools to collect, map, query, and report on road crash and related data. It contains data from all traffic crashes reported by police.

The length of roadway to be included in the crash analysis for each site was determined by the zone of influence / driver duration awareness / distance of effectiveness of each sign.

This was a difficult measure to quantify. Charlton & Baas (2006) suggests that road marking and some signs have a zone of influence of about 250m before they become ineffective and need repeating.

For an electronic sign the main effect is attention-getting. It is not perceptual adaptation that is the important aspect. Instead, the attention-capturing associates the message with the immediate road environment. The zone of influence (or duration effectiveness) is likely to depend on the physical characteristics of the road environment. For example, when an ECWS comes on, its zone of effectiveness is likely to last up until the curve exit, when it will then be perceived as a new situation. So the zone of influence is likely to last for a considerable distance if the road conditions remain unchanged, but would be very short if there is a change in the appearance of the road or a turn or an intersection downstream from the sign.

In the absence of any further pertinent research, the zone of influence for ECWS has been defined as beginning 100m before the sign (just as it becomes visible), and ending at the end of the set of curves the sign is located at, or 250m past the sign, whichever is the greatest.

Each ECWS and control site location was set up in CAS as a “site of special interest”, to allow for the site to be monitored. The data extracted from CAS (New Zealand Transport Agency, 2015b) was used to provide a before-and-after analysis for both the ECWS and control sites.

The CAS data collected for the ECWS and control sites was then manually reviewed to collect only crash data relating to the direction of travel facing the ECWS sign. Similar directional crash data was obtained for the control sites.

The data was collated into a spreadsheet to show crash numbers and severity, before and after, installation of the ECWS. The matched control sites have similar before-and-after data using the same installation date as the matched ECWS site. Each ECWS and control site has 3 years of before-and-after crash data. All crashes have been used as the ECWS effects on vehicles to slow them down will assist in reducing head-on and intersection related crashes as well as run-off-road crashes.

Speed Data

Before-and-after speed surveys were undertaken at seven ECWS sites, in order to measure the effect of the sign on changing speeds. Unfortunately these were the only sites that had speed surveys undertaken before installation, so site selection was biased.

Speed tubes were installed for one week before installation of the sign, and then again for another week approximately 3 months after installation, although this varied from site to site. Additional one week speed surveys were undertaken in May 2015 at five of the sites, about five years after installation. The remaining two sites are no longer operational.

The actual positioning of the tubes varied from site to site, but the intention was to locate them close to the location of the ECWS. This allows each driver time to view the existing advance warning signs (and the new ECWS) and react accordingly and slow down for the curve. The tubes were placed in the same location for each site for both before and after surveys.

The speed surveys recorded the speed of all vehicles, and calculated the mean and 85th percentile speeds.

RESULTS

Figure 2 shows the overall before-and-after installation crash numbers at the 27 ECWS and control sites:

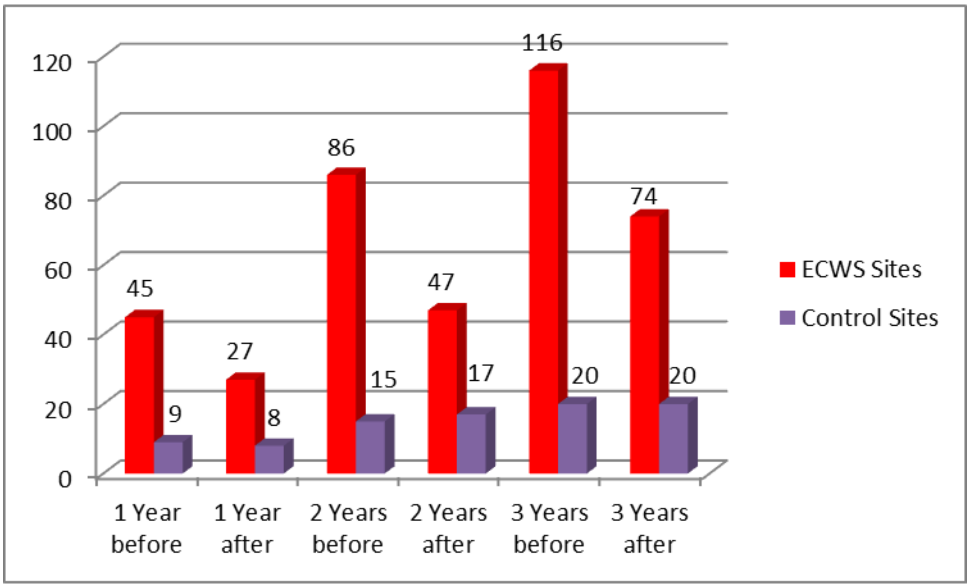

Figure 2: All Crashes

The chart above indicates the installation of ECWS has had a positive effect on reducing crash numbers compared to the control sites. There is a reduction of total crashes at ECWS sites of 18 (38%) when comparing one year before-and-after crash data, a reduction of 39 (45%) crashes for two years before and after, and a reduction of 45 (39%) crashes when comparing 3 years before and after crash numbers (a 26.5% probability that the reduction in crashes is due to chance when compared with control sites is not statistically significant, meaning not all of the crash reductions can be attributed to ECWS). The control sites show little or no variation in crash numbers, although the numbers are lower to begin with, so the results should be viewed with caution.

Figure 3 shows the DSI crashes at the 27 ECWS and control sites before and after installation of the ECWS:

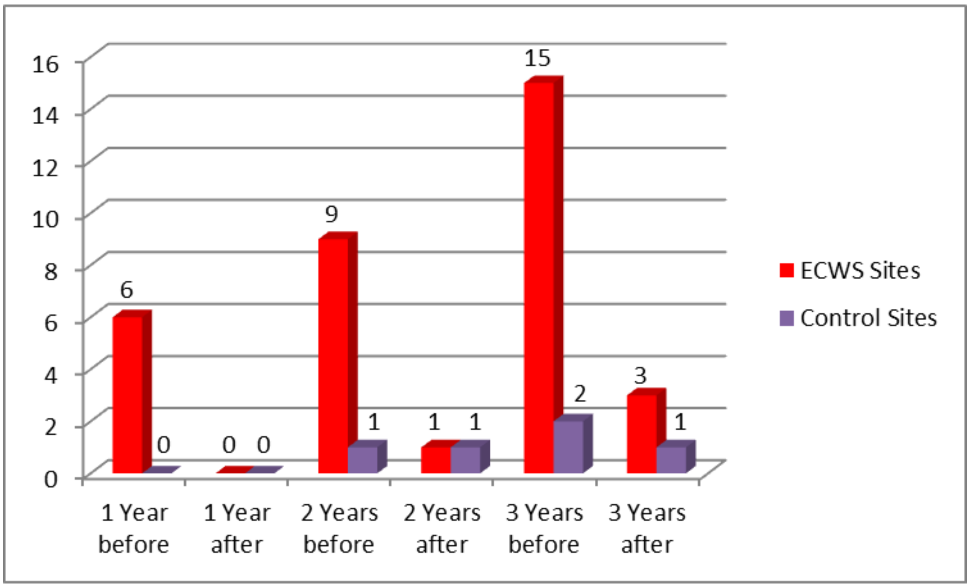

Figure 3: DSI Crashes

The above data shows a decrease of 12 (80%) DSI crashes at ECWS sites in the three years after installation compared to the three years before installation. Again, these numbers are very low and should be viewed with caution.

Additional to the data presented above, the fifteen DSI crashes in the three years before installation of the ECWS resulted in a total of 24 high severity casualties. The three DSI crashes after installation resulted in only three high severity casualties, a reduction of 21 (87.5%) casualties.

Seven ECWS locations had speed tubes installed before and after installation of the signs so as to gain some evidence of their effectiveness in reducing vehicle speeds (and therefore crashes and crash severity). Data obtained from these speed surveys included mean and 85th percentile speeds.

Figure 4 shows before-and-after speed data recorded from three sites in the Bay of Plenty in 2010. All three of these ECWS are located in a 100 km/h speed limit zone.

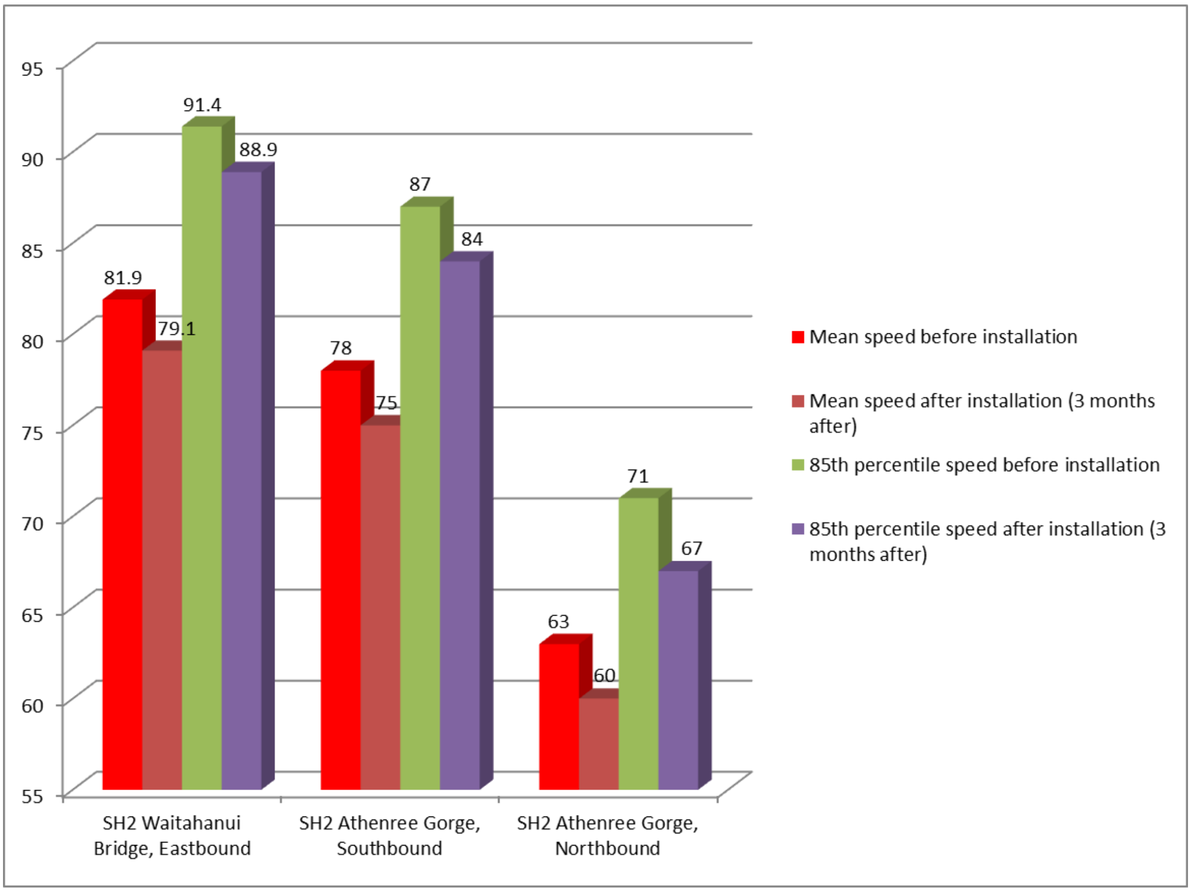

Figure 4: Before and After Speed Data for three ECWS in Bay of Plenty

As shown in the above figure, there was a reduction in mean and 85th percentile speeds of between 2 and 4 km/h (a 3% to 5.6% reduction).

The ECWS at Athenree Gorge are no longer operational. Tubes were laid down at the SH2 Waitahanui Bridge location in May 2015 to obtain up to date speed data. The recorded mean speed was found to be 81 km/h (a 1% reduction compared to the “before” installation speeds), while the 85th percentile speed was calculated to be 92.5 km/h (a 1% increase).

Figure 5 shows speed data before and three months after installation of ECWS at four sites in the Waikato region, as recorded in 2009 and 2010. Up to date speed surveys were also undertaken in May 2015 and this data is included in the table.

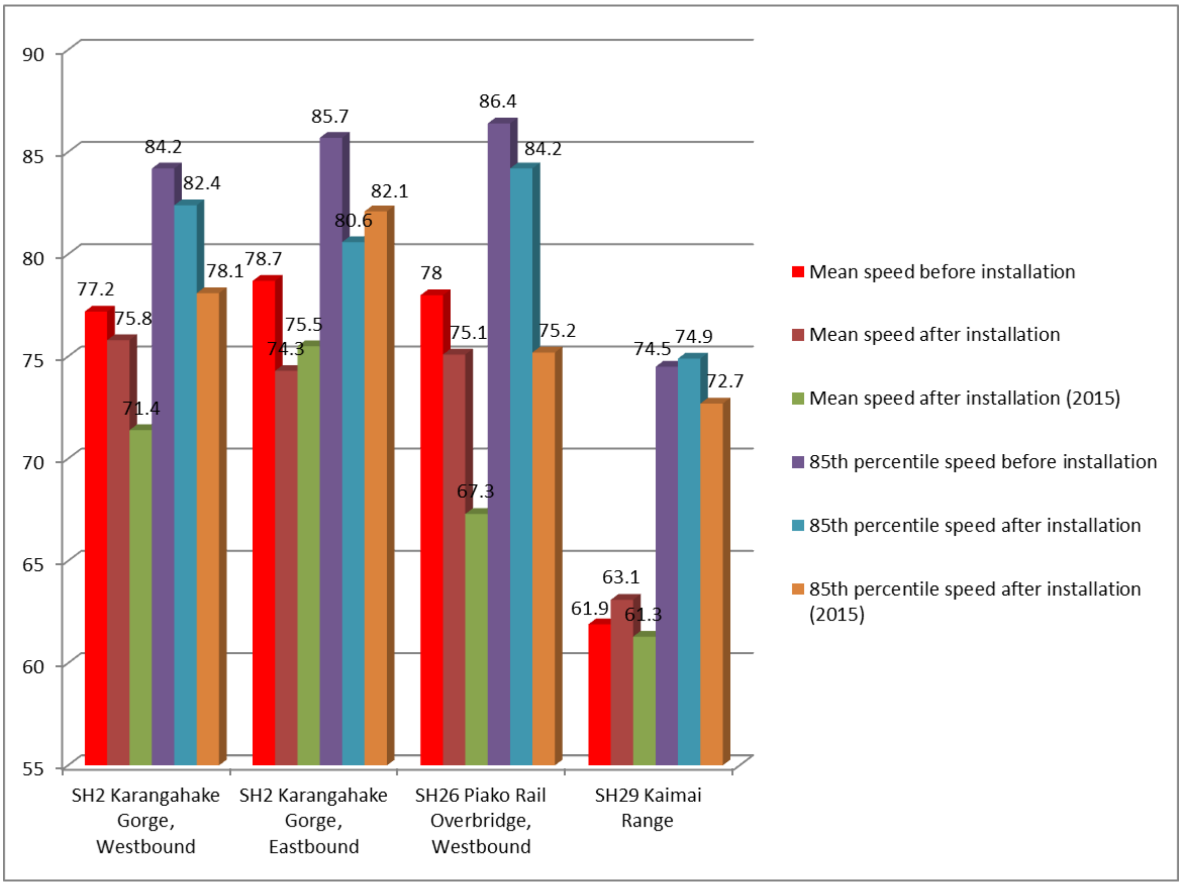

Figure 5: Before and After Speed Data for four ECWS in Waikato

The above table indicates immediate reductions of between 1 and 5 km/h in mean and 85th percentile speeds from three of the signs, with the SH29 Kaimai ECWS recording a slight increase in speeds. The 2015 speed data shows all mean and 85th percentile speeds have decreased compared to the "before" installation figures (these results are all statistically significant).

Overall, the introduction of ECWS at various sites around the country resulted in an average mean speed reduction of 2.3 km/h and an average 85th percentile speed reduction of 2.6 km/h immediately after installation of the signs. The up to date speed surveys carried out in 2015 show an average mean speed reduction of 4.3 km/h and an average 85th percentile speed reduction also of 4.3 km/h.

COST BENEFIT ANALYSIS

The costs to install an ECWS vary region to region, and also depend upon traffic management costs for the various levels of state highway. Typically, the cost to install one ECWS is approximately $17,500, and is broken down as follows:

- Electronic Sign $12,000
- Pole and socket $1,500
- Installation and commissioning $2,000
- On-site warranty $500
- Installation of socket/foundation/traffic management $1,500

The above prices (excluding GST) are based on the sign being solar powered. Prices include the cost of the solar panel, batteries and charger. Signs that are connected to the electric supply will typically be cheaper in the short term, but will have on-going electricity costs. The majority of the installed ECWS are solar powered due to their rural locations as access to mains electricity is limited.

In terms of on-going maintenance costs, it has been found that the batteries in solar powered signs need to be replaced about every three years; at a cost of around $600 (each sign has six batteries at a cost of around $100 each). Other on-going maintenance costs include full replacement if a sign is vandalised or broken. This costs around $14,000. Call-outs to adjust the brightness and speed setting of the sign cost from $200 to $1,000 depending on the level of traffic management required at each site.

In order to determine the actual benefits obtained from the installation of ECWS, an economic appraisal has been undertaken. A 6% discount rate and a 40 year analysis period were used. The base date for costs was 1 July 2014, and time zero was 1 July 2015. Comparing crash data for the three years before installation of ECWS with the three years after installation, there were 15 high severity crashes before installation with an 80% reduction after; 26 minor injury crashes before, with a 27% reduction after; and 75 non-injury crashes before with a 36% reduction after.

The net present value of the total costs for installation and maintenance of the 27 ECWS was $678K. The overall net present value of the benefits of crash reduction savings was $73M, giving a benefit cost ratio (BCR) of 126, with a first year rate of return of 1093%. These are remarkable returns for little investment and illustrate that spending millions on realignments to reduce crash numbers and severity is not always warranted or required.

DISCUSSIONS

When comparing all crashes in the three year periods before and after installation, there was a reduction of 36%, with death and serious injury crashes reduced by 80%. This seems to correlate well with the research undertaken by Robinson and Knapp (2012), Bertini et al (2006) and Austroads (2014), where data showed 30 to 35% crash reductions.

The installation of the ECWS appears to have been effective in reducing vehicle speeds by around 4 to 5 km/h. Data from this research report compares well to and corroborates the results from previous research discussed in the literature review of 5 to 6km/h (Kortegast and Gardner, 2010; Pike et al., 2013; Robinson and Knapp, 2012; Bertini et al., 2006).

The crash and speed reductions cannot all be attributed to ECWS. Enhanced police enforcement, regular maintenance of state highway surfaces, and improved signage and markings have also assisted in reducing speeds and the number and severity of crashes at the ECWS and control sites (also perhaps general driver awareness / behaviour changing over time/ targeted road safety campaigns, etc.).

Not all ECWS sites had high severity crashes or indeed any crashes before they were installed. Further justification for the installation of these signs at these locations is needed in order to invest in them and to establish guidelines for consideration (over-exposure to ECWS as they may lose their effectiveness, e.g.: if every curve had one – may be most effective if only used at high-injury-risk sites).

CONCLUSION

Data from ECWS sites shows reduced crash numbers of 36% when comparing the three years before installation with the three years after installation. In the same period, DSI crashes reduced by 80%. These crash number reductions are significant, with DSI crash reductions the most substantial.

The results of the vehicle speed analysis indicate reductions of up to 5 km/h in mean speed and 85th percentile speeds where ECWS have been installed.

It appears that dynamic vehicle activated signs such as ECWS can clearly influence drivers to reduce speed, where existing static signs have had less of an effect on driver behaviour.

Due to their effect in reducing crash numbers and vehicle speeds, ECWS should continue to be used as a tool to reduce fatal and serious injury crashes at high-risk out of context curves on the roading network in New Zealand.

Recommendation for Future Research

To build on the findings of this study, it is imperative that full evaluations are undertaken each and every time these signs are to be installed, including a full before-and-after speed and crash analysis, to ensure they are fit for purpose and provide value for money and a strong benefit cost ratio.

Further research should be undertaken to confirm the effects of confounding factors such as traffic flow, vehicle composition (are more cars crashing than other vehicles?), road environment (is adequate sight distance available through the curves?), seasonal effect, driver characteristics and whether more crashes are occurring on left or right curves. It would be appropriate to delve deeper into the crash and speed data to confirm these effects.

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