# Redland Smart Signs and Smart Messages:

# A Driver Behaviour Change Project – Year 2

# Final Report (2019-2020)

Report prepared for Redland City Council

July 2020

Report published by Griffith University's Applied Road Ecology Group

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Additional copies may be obtained from the Environmental Futures Research Institute, Griffith University, Nathan, Qld 4111.

This publication should be cited as: Appleby, R., Ransome, L., Blacker, A., and Jones, D. (2020). Redland Smart Signs and Smart Messages: A Driver Change Behaviour Project – Year 2 Final Report. Prepared for Redland City Council. Applied Road Ecology Group, Environmental Futures Research Institute, Griffith University, Nathan, Qld.

# Executive summary

Koala populations throughout south-east Queensland are rapidly declining, and vehicle strike is recognised as a major source of artificial koala mortality. Major road infrastructural approaches to mitigation, such as fauna passages and fencing, whilst often successful at a local scale, are expensive to implement and maintain, and limited in applicability, whereas vehicle strike is ubiquitous. In an attempt to explore additional approaches to mitigating vehicle strike, the Redland City Council has instituted a series of programs aimed at educating and informing residents about the plight of koalas, and is exploring the role that signage might play in helping to reduce strike events. New signage technology offers an opportunity to dynamically interact with drivers and reinforce beneficial behaviours, particularly reducing speed. A study was originally initiated in 2018 on three streets in the 'Ormiston koala safe neighbourhood', with results suggesting that koala-specific, variable messaging signage (VMS) outperformed generic message signage in encouraging a reduction in overall average speed as well as in relation to the average speed of vehicles traveling over the posted speed limit (speeders). The study was extended into 2019/2020, with an additional sign design, and rotations of each model to each street were incorporated into the experimental design. Like the previous study phase, interactive signs were found to consistently reduce overall and 'speeder' average speeds and '85th percentile' (speed recordings at the highest end of observations) speeds (see: https://tinyurl.com/y9lyykdv). In all but two cases (where average speed increased slightly), reductions in speed during treatment periods for a given sign and location equated to between a 1.68-16.74% drop compared to overall pre-treatment average speeds. And similarly, in all but two cases (again, where average speed was unchanged or increased slightly), the same pattern was observed for vehicles in the 85th percentile, with reductions in average speed of between 0.73-12.81%. The impact of signs was clearest for two (Jenoptik) models of sign capable of measuring speed before and after vehicles passed by signs, where in every case, average speed after signs was always lower than before signs, and often substantially. Encouragingly, based upon pre-treatment period observations, most drivers in Ormiston were already travelling below the speed limit. There were technical and logistical issues that limited our ability to draw any strong conclusions, but it appears that all interactive signs trialled during this study to-date do encourage most drivers to reduce their speed, and different sign types or features may appeal to different drivers. Signs therefore do appear to offer benefits in terms of reducing vehicle speed, but further research is recommended in order to better ascertain how crucial variables such as habituation, and strike events themselves, are influenced by signs.

# Acknowledgements

The Redland Smart Signs project was commissioned by Redland City Council as part of their koala conservation safe neighbourhoods initiative. Cathryn Dexter, Project Officer – Koala Conservation Program was instrumental as the project lead. Cathryn initiated the Smart Signs project and managed all those involved in implementing the project. We are very grateful to Cathryn for all her support throughout the study. We are also grateful to Mario Conde, Michael Knight and Michael Fahey from ITS/Artcraft, Andrew Drysdale from Jenoptik, Rudy Budianto from RoadTek, Darren Biles and David Shearman from Queensland Civil Group and Rex Roebeck and Candy Daunt from Redland City Council.

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# 1. Introduction

Koala populations throughout south-east Queensland (SEQ) are rapidly declining, with Rhodes et al. (2015) suggesting an approximately 80.3% decline of the population in the koala coast region between 1996 and 2014.

Vehicle strike (koalas being struck by vehicles on roads) is recognised as a major source of artificial koala mortality (Gonzalez-Astudillo et al. 2017; McAlpine et al. 2015; Niehaus and Wilson, 2018; Tisdell et al. 2017), yet few interventions are available for mitigation. Commonly employed measures such as fauna crossing structures (fauna bridges, overpasses, underpasses etc.) and fencing, whilst often successful (Dexter et al. 2016; McGregor et al. 2015, 2017), are also costly and virtually impossible to employ at a scale complimentary to that of strikes.

Infrastructural approaches such as fencing and fauna passages are primarily designed to prohibit the ability of animals to enter a road. However, vehicle strike mitigation may also be viewed from the perspective of drivers and their behaviour. Methods that encourage drivers to be vigilant for the presence of wildlife on or near roads, and to drive more cautiously and reduce speed, represent a potentially viable approach to reducing strikes.

Wildlife signage is one of the most widely employed attempts at mitigating strikes, but generally, there has been little evidence of success in this regard (Glista et al. 2009; Huijser et al. 2015). In their comprehensive review of approaches to conserving koalas, which readily identified vehicle strike as a driver of decline, McAlpine et al. (2015) made no mention of signs. Indeed, previous research has suggested that signs do not represent a viable means of reducing strike events involving koalas (Dique et al. 2003).

New signage technology has become available that allows for real-time messaging to drivers that can be tailored and dynamic, providing useful feedback to drivers about their driving behaviour, particularly in relation to speed. Such dynamic signage has been consistently demonstrated to both reduce driver speed, and collisions, and can do so cost-effectively (Wu et al. 2020).

To-date, there has been little exploration of the technology in relation to reducing wildlife vehicle strikes directly, but Bond and Jones (2013) conducted a survey of drivers in the SEQ region in relation to sign characteristics, including dynamic designs. They found that speed-activated dynamic or variable messaging signs rated very highly amongst participants because signs were interactive (Bond and Jones 2013).

Being able to provide such feedback to drivers allows for a potentially important opportunity to encourage appropriate driving, using messaging that targets specific responses. For instance, drivers that are speeding can be reminded to slow down, whereas drivers that are already travelling at appropriate speeds can have such behaviour reinforced with messages that thank them or convey a similar congratulatory sentiment.

A major potential problem for signs is that even if they are effective initially, effectiveness may decrease over time, because drivers learn to ignore them (Huijser et al. 2015), a process known as habituation. This involves a generally simple, and largely unconscious behavioural phenomenon whereby repeated exposure to a benign (unimportant) stimulus results in a reduction in response.

However, in the context of signs, there are a series of additional considerations that may influence and even limit habituation, such as whether drivers themselves believe signs actually reflect important warning information (Huijser et al. 2015). This suggests that additional strategies are sometimes required in order to prevent habituation, an important one being broader education programs that inform drivers about signs, what they are for and why they are being used.

Thus, even if drivers do not themselves see wildlife such as koalas on or near roads, which might lead to them to believe signs are unimportant, such additional information can bolster driver awareness about, and responses to, signs and help limit habituation.

To this end, the Redland City Council (RCC) has instituted a multi-year sign trial to investigate the effectiveness of signs in reducing vehicle speeds (and by extension, strike events), in conjunction with a suite of other community engagement projects aimed at raising awareness about the plight of koalas. Blacker et al. (2019, see: https://tinyurl.com/y9lyykdv) reported on initial results of a pilot investigation of dynamic koala signs in three streets in the Redlands, and here, we provide a further summary of the additional results to-date.

# 2. Methodology

## 2.1 Study sites

Three streets within the Ormiston neighbourhood (Redland City) were chosen for this study. Two would be classed as largely residential (Starkey Street, Wellington Street), while the other is local link road in the area (Sturgeon Street). On each street, two locations, one corresponding to each direction of travel, were chosen and signs were installed. Figure 1 provides a map of the approximate sign locations on particular streets.


**Figure 1.** A map showing the locations of signs on three streets in Ormiston, Redlands.  symbols indicate the positions of roundabouts on Sturgeon Street. Red arrows show the direction of vehicle travel for a particular sign/site.

## 2.2 Koala vehicle strike data

To the best of our knowledge, no koalas have been hit by vehicles along any trial street since before the previous pilot study began (Blacker et al. 2019) or throughout the current phase of the study (which began on 30 September 2019 and ended on 20 March 2020 - see sign rotation schedule section below for further information on the current study period). One strike appears to have occurred in the Ormiston neighbourhood more generally, on Hilliard St, in between the pilot and current study, on or around 6 August 2018 (RCC unpublished data).

## 2.3 Wildlife warning signs

Three types of signs were trialled, from two different manufacturers/suppliers. Two were dynamic message signs (Jenoptik) that reported tailorable messages to drivers via an LED display panel. In each case, the display panel was the same, with the primary variation between the two types being the passive messaging displayed on each. A 'generic' version of the sign (named Jenoptik 'smiley') featured a high visibility border and the words: "DRIVE SAFELY", whilst a koala-specific version (named Jenoptik 'koala _smiley') featured the image of a koala with the words: "KOALA CROSSING". Figure 2 shows each version of the Jenoptik signs side-by-side for comparison.


**Figure 2.** Jenoptik brand named for this project as 'smiley' (left) and 'koala_smiley' (right) models of dynamic (variable) message signage.

The third sign type (ITS/Artcraft) featured two LED flasher lights that flashed on and off whenever a vehicle was detected exceeding a specifiable speed threshold. The posted speed limit was also displayed (and could be replaced depending on the speed of a given street) along with a smaller version of the same koala image and message featured in the Jenoptik koala smiley sign and a high visibility banner with the words: “WILDLIFE ZONE” (see Figure 3).

The Jenoptik signs were capable of recording the speed of a vehicle both before and as it passed the sign, providing a direct comparison. Data were also individually recorded vehicles such that one row of data pertained to one vehicle. The ITS/Artcraft sign only recorded the speed of vehicles as they approached signs, and data were collated into ‘bins’ based upon a speed interval (e.g. between 50-60km/hr) and a time period (hourly).


**Figure 3.** ITS/Artcraft koala sign incorporated into the present study phase

## 2.4 Dynamic (Variable) Messaging

Jenoptik signs were capable of dynamically changing (often referred to as: ‘variable’) messaging conveyed to drivers depending on their speed. Figure 4 provides an example of the different messages drivers received at different speeds.


**Figure 4.** An example of the dynamic, variable sign messaging that greeted drivers given certain, measured vehicle speed thresholds, capable with the Jenoptik models. In this example, messaging was tailored to a 50km/hr posted speed limit zone. For a 60km/hr posted speed limit zone, each threshold was increased by 10km/hr. The green koala symbol which greeted drivers if they were recorded to be driving under 45km/hr (or under 55km/hr in a 60km/hr zone) was unique to the Jenoptik koala_smiley model (i.e. the generic Jenoptik smiley model featured a green, round 'smiley' face as pictured for the other speed thresholds).

## 2.5 Sign rotation schedule

In an effort to explore any potential effects of particular locations on sign performance, each of the three sign designs was tested on each street. Table 1 provides a summary of the various study periods including the dates of rotations, and Table 2 provides a more detailed description for each individual sign.

**Table 1.** An overall summary of the various periods during the study and sign rotation dates

| Phase | Period (days) | Start (Revised) | Finish (Revised) | Description |
|---|---|---|---|---|
| Covered | 21 | 30/09/2019 | 21/10/2019 | Signs installed and covered – preliminary data collection to identify any issues with the signs and rectify them prior to collection of pre-treatment data |
| Pre-treatment | 37 | 21/10/2019 | 26/11/2019 | Signs covered – recording vehicle speed for pre-treatment period |
| Treatment 1 | 39 | 28/11/2011 | 5/01/2020 | Signs uncovered – recording vehicle speed for first treatment period |
| Treatment 2 | 42 | 6/01/2020 | 17/02/2020 | Signs rotated – recording vehicle speed for second treatment period |
| Treatment 3 | 31 | 18/02/2020 | 19/03/2020 | Signs rotated – recording vehicle speed for third treatment period |
| Remove | NA | 20/03/2020 | NA | All signs removed any time after 20/03/2020 |

**Table 2.** Detailed summary of each sign in relation to specific location and rotation period

| Sign Number | Sign Type | Pre-treatment and Treatment 1 Location | Treatment 2 Location | Treatment 3 Location |
|---|---|---|---|---|
| 14370 | Jenoptik smiley | Sturgeon St (west) | Wellington St (south) | Starkey St (south) |
| 14361 | Jenoptik smiley | Sturgeon St (east) | Wellington St (north) | Starkey St (north) |
| 16720 | Jenoptik koala_smiley | Starkey St (north) | Sturgeon St (east) | Wellington St (south) |
| 16718 | Jenoptik koala_smiley | Starkey St (south) | Sturgeon St (west) | Wellington St (north) |
| K001_01 | ITS koala | Wellington St (north) | Starkey St (north) | Sturgeon St (east) |
| K001_02 | ITS koala | Wellington St (south) | Starkey St (south) | Sturgeon St (west) |

## 2.6 Technical and data issues

Signs operated as expected for the majority of the time and enough data were collected during each study period (pre-treatment and treatment periods) in order to make reasonable comparisons. However, there were times when one or more signs malfunctioned, or where other issues arose, resulting in compromised or lost data. These issues are detailed in Appendix 1 and data losses are summarised in Appendix 2.

## 2.7 Data processing and quality checks

Online web portals were regularly checked to ensure signs were operational, and radar outputs and summary data were regularly examined throughout the study period. Data files were downloaded via the Internet, or were provided upon request by sign providers, usually at the end of each treatment period.

Jenoptik sign raw data in the form of .GRS files were exported from the Sierzega GRS 5.2 software program as .txt files then collated by sign and treatment period in Excel. ITS sign raw data in the form of .dat files were imported to the software program Houston Radar Stats Analyzer and trimmed to the dates of each treatment period, then the resulting summary reports were exported to Excel.

During data processing, additional data variables were added or calculated, which were of interest for analyses or assisted in finding data errors. Jenoptik data were also checked for anomalies by graphing the average daily car speeds for each sign and treatment period to look for large spikes or dips in speed. Such anomalous data, including those resulting from technical issues, were removed from datasets (see anomalies detailed in Appendix 2: Technical and data issues). Dates on which signs were rotated between sites at the start of each new treatment period were also removed from the dataset in case of any effects of road crew presence on driver behaviour.

ITS sign manufacturers advised that raw data (i.e. timestamped recordings of individual car speeds) were not available due to the design of the system so it was not possible to check for anomalies in as thorough a manner as for the Jenoptik sign data. It would be possible to manually trim the full datasets down to each day of each treatment period in order to export daily averages from the software, however given the time-consuming nature of this process and the time constraints of this project, this was unfortunately not possible for the purposes of this report. However known dates where anomalous data were expected were removed from the ITS datasets, for example where signs had been showing incorrect speed limits for a period of time before being corrected (see Appendix 2 for details).

## 2.8 Data analyses

Due to the highly variable and potentially confounded nature of the data, we chose to present results using basic descriptive and graphical methods, avoiding conventional modelling and statistical tests. Such tests are, in this circumstance, potentially erroneous and therefore unlikely to add confidence in interpreting any differences between sign performance, one of the principle aims of these trials. For instance, given the proximity of trial roads to one another, it is likely, but entirely unclear to what extent, the same drivers drove on two or all three of the trial roads within the same pre-treatment/treatment periods. Such unknown confounding factors and how or if it varied between the pre-treatment and treatment periods undermines the validity of many traditional tests. As we will demonstrate, there is also considerable variation within particular signs at particular times, which itself is not necessarily consistent over the entire sampling period.

An additional source of potential, but again, unknowable error derives from the different radar units in signs from the two manufacturers, and how the subsequent radar data are collated. Whilst it would be expected that raw speed measurements between two models of radar system would be approximately equivalent, any difference in, for example, the distances at which speed measurements are taken are likely to result in different outcomes. Side-by-side sign radar comparison/calibration under controlled conditions was not possible during the current study, but would be necessary to rule out this potential source of error. As signs also collate measured speed data differently, direct comparisons of sign performance between the two manufacturers also presented challenges.

Thus, rather than attempt a direct inferential comparison of sign performance, we have instead focussed on providing a broader assessment of face-value performance in uncontrolled conditions. Due to the caveats we have outlined above, we suggest that some caution is required in interpreting results, although as will be seen, the overall consistency in results provides confidence.

As two speeds were recorded per vehicle for the Jenoptik signs, 'V1' is the speed recorded as the driver approaches the sign and 'V2' is the speed recorded as the driver passes the sign. Summary statistical analyses for the Jenoptik signs were conducted in excel, including calculating average car speeds, average car speeds of ‘speeders’, and 85$^{th}$ percentile car speeds for each sign and treatment period. These figures were then used to calculate the change in speeds between the pre-treatment (signs covered) and treatment periods, as well as between the V1 and V2 speed within each treatment period. ITS sign data summaries were performed automatically by the software prior to exporting data summaries, including average car speed, 85$^{th}$ percentile car speed, maximum car speed and number of cars for each treatment period. Standard deviations for the ITS sign data were not available from the software’s summary. The software also exported a dataset that tallied the number of cars in each of several categorical bins of speed (e.g. 40-50 km/hr, 50-60 km/hr, etc.) in hourly blocks of time. This allowed the calculation of the percentage of recorded cars driving at or below the speed limit, as well as above the speed limit, and subsequent calculations of how these percentages changed between the pre-treatment and treatment periods.

# 3. Results

## 3.1 Pre-treatment data

For convenience, we first present global average (mean) speeds, as well as 85th percentile speeds for each individual site and sign in the pre-treatment period (Table 3). For Jenoptik signs, we included speeds both before (V1) and after (V2) vehicles had passed signs.

**Table 3.** Pre-treatment overall average and 85th percentile speeds for every sign at street location, along with corresponding posted speed limits.

| Site | Posted speed limit (km/hr) | Average speed (km/hr) (average V1 speed for Jenoptiks) | Average speed (km/hr) (average V2 speed for Jenoptiks) | 85th percentile speed (km/hr) (V1 speed for Jenoptiks) | 85th percentile speed (km/hr) (V2 speed for Jenoptiks) |
|---|---|---|---|---|---|
| Sturgeon St east | 60 | 52.79 | 49.35 | 59 | 56 |
| Sturgeon St west | 60 | 55.76 | 53.68 | 62 | 60 |
| Starkey St south | 60 | 55.66 | 55.65 | 60 | 60 |
| Starkey St north | 60 | 55.79 | 55.72 | 61 | 61 |
| Wellington St north | 50 | 47.95 | NA | 56.2 | NA |
| Wellington St south | 50 | 45.26 | NA | 54.8 | NA |

In all cases, pre-treatment average speeds are below posted speed limits, and in five cases, 85th percentile speeds are also at or below posted speed limits. As signs were covered during the pre-treatment period, it is impossible for drivers to have known the exact information the signs conveyed, but they are likely to have been aware of sign presence. We suspect that the before and after speed differences observed on Sturgeon Street relate considerably to vehicles approaching roundabouts, and necessarily having to slow down.

Table 4 further summarises observations during the pre-treatment period, this time including standard deviation, minimum and maximum daily averages as well as vehicle counts for a given sign and location.

**Table 4.** Overall mean, standard deviation, minimum and maximum and vehicle count numbers for all signs in the pre-treatment period. Results in black (bold) are vehicle numbers that are unexpectedly low for a given site.

| Site | Posted speed limit (km/hr) | Sign type/ID | Average speed (km/hr) (average V2 speed for Jenoptiks) | Standard deviation | Minimum daily average speed (km/hr) | Maximum daily average speed (km/hr) | Sample size (number of cars) |
|---|---|---|---|---|---|---|---|
| Sturgeon St east | 60 | Jenoptik smiley (14361) | 49.35 | 7.06 | 48.61 | 50.54 | 231,291 |
| Sturgeon St west | 60 | Jenoptik smiley (14370) | 53.68 | 7.56 | 52.74 | 55.16 | 177,630 |
| Starkey St south | 60 | Jenoptik koala_smiley (16718) | 55.65 | 5.03 | 54.55 | 56.46 | 45,377 |
| Starkey St north | 60 | Jenoptik koala_smiley (16720) | 55.72 | 5.08 | 54.97 | 56.74 | 99,225 |
| Wellington St north | 50 | ITS koala sign (K001_01) | 47.95 | NA | NA | NA | **8,118** |
| Wellington St south | 50 | ITS koala sign (K001_02) | 45.26 | NA | NA | NA | **1,281** |

## 3.2 Comparison of pre-treatment and treatment data

Table 5 provides a summary of all average speed recordings for each sign at each street location, along with other useful information such as standard deviation and vehicle numbers where available, all grouped into three treatment periods: treatment 1, treatment 2 and treatment 3. Colour codes are provided so that each sign pair can be easily found in a given treatment period.

**Table 5.** Summary of car speed data for six signs (two Jenoptik 'smileys', two Jenoptik 'koala_smileys', and two ITS koala signs) across three treatment periods. Values in red (bold) indicate an average speed that was higher than the pre-treatment average (or follow the link in blue immediately below to view full resolution version).

Full resolution version of Table 5

| | | Pre-treatment period | | | | | | Treatment 1 period | | | | | | Treatment 2 period | | | | | | Treatment 3 period | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Site** | **Speed limit** (km/hr) | **Sign type/ID** | **Average speed (km/hr)** (average V2 speed for Jenoptiks) | **Standard deviation** | **Minimum daily average speed** (km/hr) | **Maximum daily average speed** (km/hr) | **Sample size** (number of cars) | **Sign type/ID** | **Average speed (km/hr)** (average V2 speed for Jenoptiks) | **Standard deviation** | **Minimum daily average speed** (km/hr) | **Maximum daily average speed** (km/hr) | **Sample size** (number of cars) | **Sign type/ID** | **Average speed (km/hr)** (average V2 speed for Jenoptiks) | **Standard deviation** | **Minimum daily average speed** (km/hr) | **Maximum daily average speed** (km/hr) | **Sample size** (number of cars) | **Sign type/ID** | **Average speed (km/hr)** (average V2 speed for Jenoptiks) | **Standard deviation** | **Minimum daily average speed** (km/hr) | **Maximu m daily average speed** (km/hr) | **Sample size** (number of cars) |
| Sturgeon St east | 60 | Jenoptik smiley (14361) | 49.354 | 7.062 | 48.612 | 50.540 | 231,291 | Jenoptik smiley (14361) | 48.524 | 7.453 | 48.166 | 49.028 | 150,598 | Jenoptik koala_smiley (16720) | **51.478** | 6.957 | 49.567 | 52.998 | 130,519 | ITS koala sign (K001_01) | 43.22 | NA | NA | NA | 1,439 |
| Sturgeon St west | 60 | Jenoptik smiley (14370) | 53.675 | 7.556 | 52.744 | 55.159 | 177,630 | Jenoptik smiley (14370) | 52.18 | 7.187 | 51.863 | 52.558 | 169,032 | Jenoptik koala_smiley (16718) | 52.575 | 5.932 | 51.193 | 53.484 | 148,482 | ITS koala sign (K001_02) | 48.97 | NA | NA | NA | 39,898 |
| Starkey St south | 60 | Jenoptik koala_smiley (16718) | 55.65 | 5.031 | 54.552 | 56.461 | 45,377 | Jenoptik koala_smiley (16718) | 50.166 | 9.128 | 49.677 | 51.492 | 40,436 | ITS koala sign (K001_02) | 50.86 | NA | NA | NA | 4,149 | Jenoptik smiley (14370) | 46.333 | 10.042 | 45.132 | 47.339 | 109,920 |
| Starkey St north | 60 | Jenoptik koala_smiley (16720) | 55.718 | 5.082 | 54.966 | 56.741 | 99,225 | Jenoptik koala_smiley (16720) | 49.9 | 6.847 | 48.643 | 50.544 | 55,086 | ITS koala sign (K001_01) | 51.150 | NA | NA | NA | 859 | Jenoptik smiley (14361) | 50.264 | 7.673 | 49.015 | 51.409 | 126,927 |
| Wellington St north | 50 | ITS koala sign (K001_01) | 47.95 | NA | NA | NA | 8,118 | ITS koala sign (K001_01) | 45.83 | NA | NA | NA | 652 | Jenoptik smiley (14361) | 40.835 | 9.149 | 39.259 | 41.961 | 118,358 | Jenoptik koala_smiley (16718) | 46.829 | 7.804 | 45.186 | 48.172 | 72,264 |
| Wellington St south | 50 | ITS koala sign (K001_02) | 45.26 | NA | NA | NA | 1,281 | ITS koala sign (K001_02) | **45.73** | NA | NA | NA | 4,853 | Jenoptik smiley (14370) | 44.500 | 9.063 | 41.583 | 48.161 | 86,271 | Jenoptik koala_smiley (16720) | 43.152 | 9.089 | 41.285 | 50.006 | 18,898 |

As Table 5 demonstrates, in all but two cases, all overall average speeds during treatment periods were lower than pre-treatment average speeds from the same location. Minimum and maximum daily averages did appear to vary somewhat within a given period for each sign in many cases, also reflected in standard deviation values, although none appeared extreme.

It is worth mentioning again that the positions of both Sturgeon Street sign locations meant that signs were recording vehicles traveling towards roundabouts, especially noteworthy at the Sturgeon Street east location, which was approximately 50m away or less from a roundabout. In turn, this proximity to roundabouts is likely to have markedly influenced vehicle speed. The relatively large drop recorded in treatment period three at this location may, however, be more a result of the relatively low number of vehicle numbers recorded by the particular sign (K1001_01). This particular sign generally appeared to record at least one, and sometimes two orders of magnitude lower vehicle numbers at a given site in comparison to other signs at the same site (albeit in different periods). The other ITS/Artcraft sign (K1001_02) also appeared to have recorded lower vehicle numbers, particularly in the pre-treatment period, as well as treatment periods 1 and 2. Anomalous vehicle numbers such as this may unduly influence results.

In Table 6, we present the changes in observed average speeds in terms of a percentage drop (or in two cases, an actual increase) in speed compared to pre-treatment period averages.

**Table 6.** Changes in average speed between pre-treatment and treatment periods in terms of a percentage drop (or increase). Values in red highlight increases.

| Site | Speed limit (km/hr) | Treatment 1 period | | Treatment 2 period | | Treatment 3 period | | |
|---|---|---|---|---|---|---|---|---|
| | | Sign type/ID | % speed change (from PT) | Sign type/ID | % speed change (from PT) | Sign type/ID | % speed change (from PT) | Best Performer |
| Sturgeon St east | 60 | Jenoptik smiley (14361) | -1.68 | Jenoptik koala_smiley (16720) | **4.30** | ITS koala sign (K001_01) | -12.43 | ITS koala sign (K001_01) |
| Sturgeon St west | 60 | Jenoptik smiley (14370) | -2.79 | Jenoptik koala_smiley (16718) | -2.05 | ITS koala sign (K001_02) | -8.77 | ITS koala sign (K001_02) |
| Starkey St south | 60 | Jenoptik koala_smiley (16718) | -9.86 | ITS koala sign (K001_02) | -8.61 | Jenoptik smiley (14370) | -16.74 | Jenoptik smiley (14370) |
| Starkey St north | 60 | Jenoptik koala_smiley (16720) | -10.44 | ITS koala sign (K001_01) | -8.20 | Jenoptik smiley (14361) | -9.79 | Jenoptik koala_smiley (16720) |
| Wellington St north | 50 | ITS koala sign (K001_01) | -4.42 | Jenoptik smiley (14361) | -14.84 | Jenoptik koala_smiley (16718) | -2.34 | Jenoptik smiley (14361) |
| Wellington St south | 50 | ITS koala sign (K001_02) | **1.04** | Jenoptik smiley (14370) | -1.68 | Jenoptik koala_smiley (16720) | -4.66 | Jenoptik koala_smiley (16720) |

As can be seen, in almost all cases a drop in speed was recorded, with treatment period averages dropping from between 1.68% and 16.74%. The highest increase was 4.3% recorded at Sturgeon St east during treatment period 2. Again, some caution is recommended in relation to interpreting the results for ITS/Artcraft signs, and from this point forward, due to the potentially anomalous nature of the ITS/Artcraft vehicle numbers, we consider only the Jenoptik signs.

In order to examine results in more detail, we next present graphs of overall average daily V1 (before) and V2 (after) speeds for each sign and treatment period, where available (see Figures 5 through to 8).

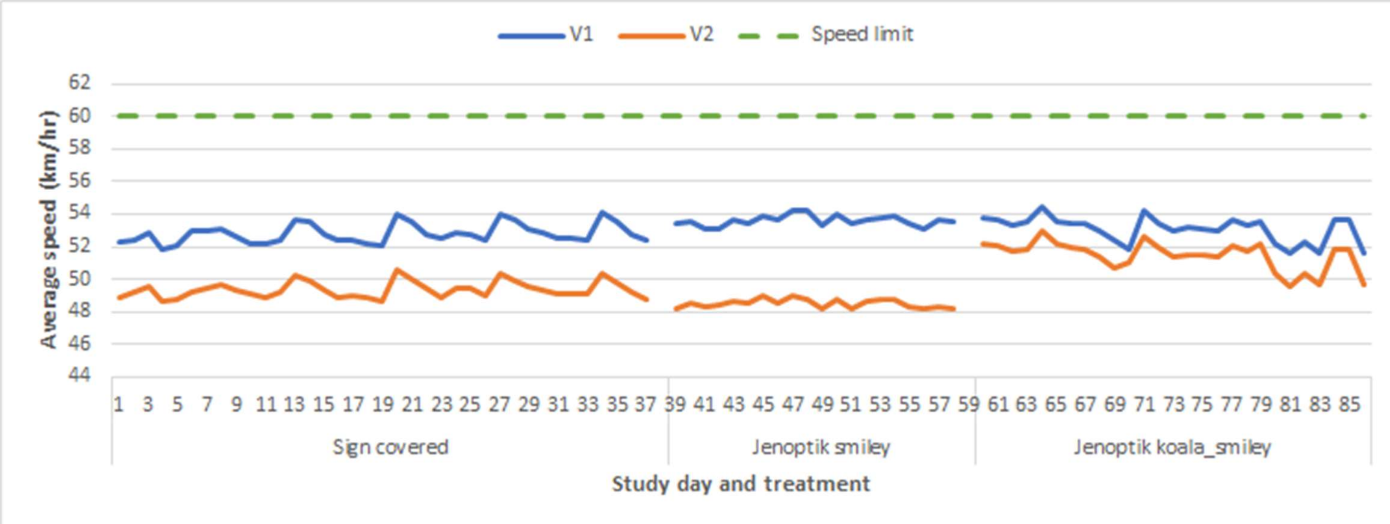



**Figure 5.** Sturgeon Street east average daily car speeds during the pre-treatment period when a sign was present but covered; during the treatment 1 period when Jenoptik smiley 14361 was present; and during the treatment 2 period when Jenoptik koala_smiley 16720 was present. The treatment 3 period, when ITS koala sign K001_02 was present, is not shown due to a lack of average daily speed data for this sign. Note the pre-treatment plot shows two separate lines for V1 and V2 speeds, probably due to cars slowing as they approached a roundabout.

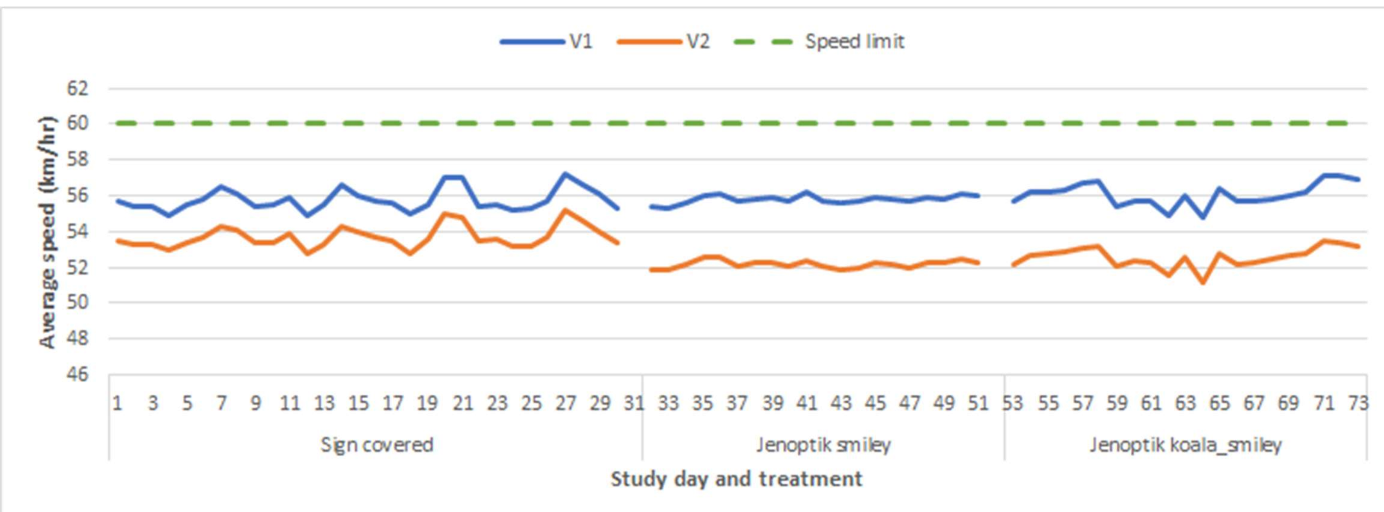



**Figure 6.** Sturgeon St west average daily car speeds during the pre-treatment period when a sign was present but covered; during the treatment 1 period when Jenoptik smiley 14370 was present; and during the treatment 2 period when Jenoptik koala_smiley 16718 was present. The treatment 3 period, when ITS koala sign K001_02 was present, is not shown due to a lack of average daily speed data for this sign. Note the pre-treatment plot shows two separate lines for V1 and V2 speeds, probably due to cars slowing as they approached a roundabout.

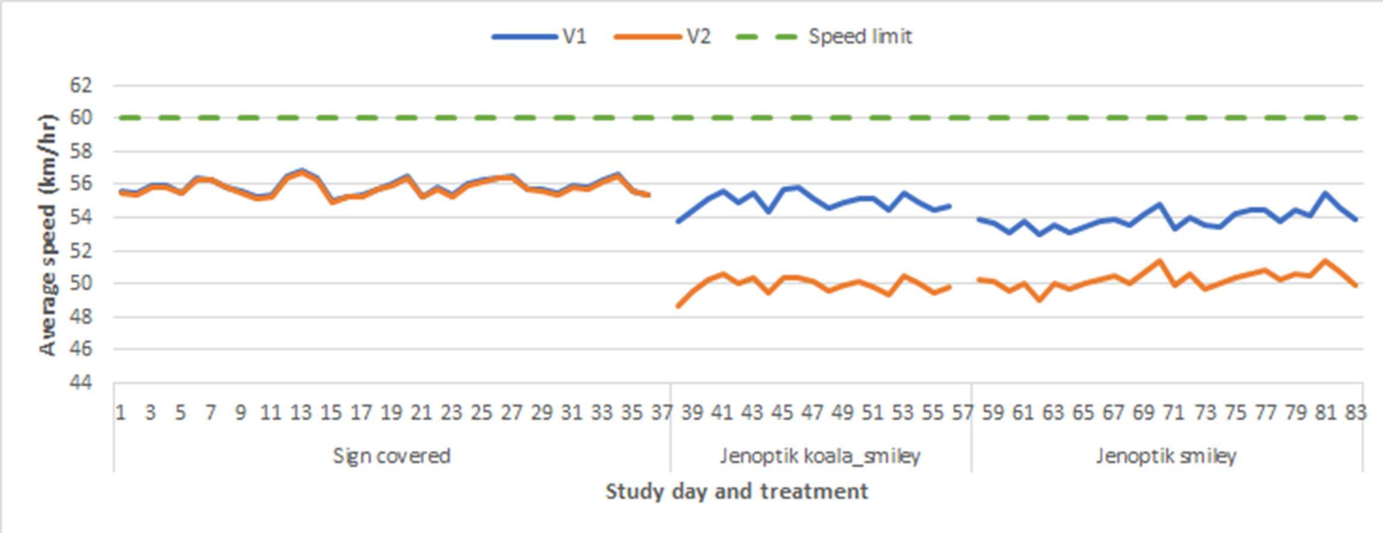



**Figure 7.** Starkey Street north average daily car speeds during the pre-treatment period when a sign was present but covered; during the treatment 1 period when Jenoptik koala_smiley sign 16720 was present; and during the Treatment 3 period when Jenoptik smiley sign 14361 was present. The treatment 2 period, when ITS koala sign K001_01 was present, is not shown due to a lack of average daily speed data for this sign. Note the pre-treatment plot shows only a single line as V1 and V2 speeds were so similar.

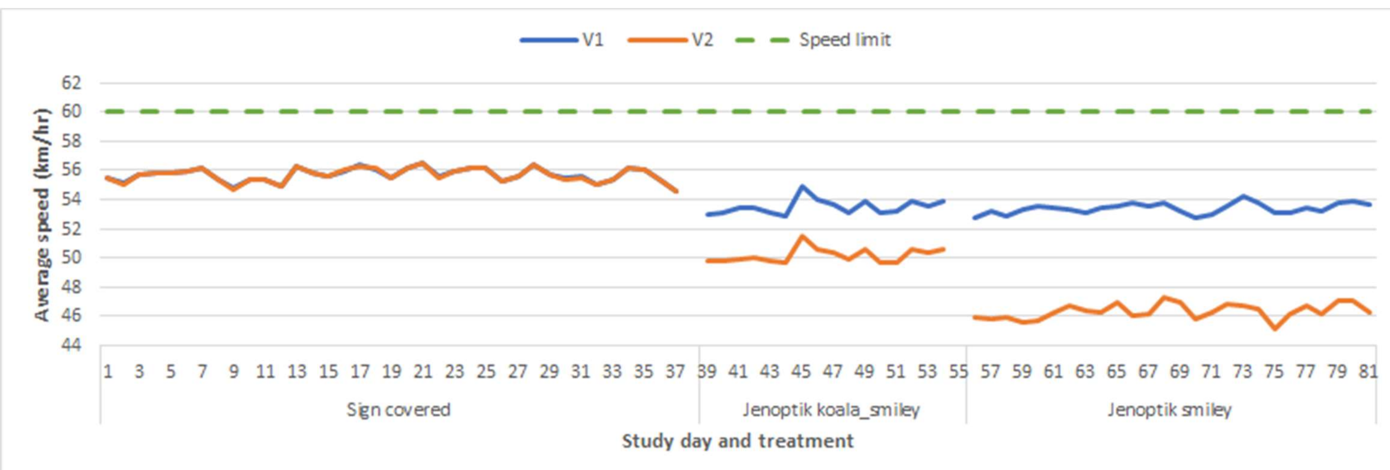



**Figure 8.** Starkey Street south average daily car speeds during the pre-treatment period when a sign was present but covered; during the treatment 1 period when Jenoptik koala_smiley sign 16718 was present; and during the Treatment 3 period when Jenoptik smiley sign 14370 was present. The treatment 2 period, when ITS koala sign K001_02 was present, is not shown due to a lack of average daily speed data for this sign. Note the pre-treatment plot shows only a single line as V1 and V2 speeds were so similar.

In every case, all V2 average speeds on any given day within a given treatment period were lower than V1 speeds. Also, in many cases (although not all, see: Sturgeon Street east, Jenoptik koala_smiley treatment period), the gap between V2 and V1 average speeds increased notably in treatment periods, compared to the pre-treatment period.

There is also, generally, a consistent pattern in covariation in both before and after speeds in many cases (both V1 and V2 line plots for a given sign in a given treatment period tend to rise and fall together across the period), most notable when speed changes between days are stark.
Note also that for Sturgeon and Starkey Streets, no daily average V1 speed was ever above the posted speed limit, even during the pre-treatment period when signs were covered, meaning on average, drivers at these locations don't tend to speed. There were sporadic cases for both streets in the raw data, but these appeared largely anomalous, and usually pertained to relatively brief periods of time. Some examples of such anomalous observations are provided in the appendices.

As the pre-treatment period at Wellington Street began with ITS/Artcraft signs it was not possible to plot a similar graph including this period for the Wellington Street signs. However, plots for the second and third treatment periods still showed interesting results (see Figures 9 and 10).

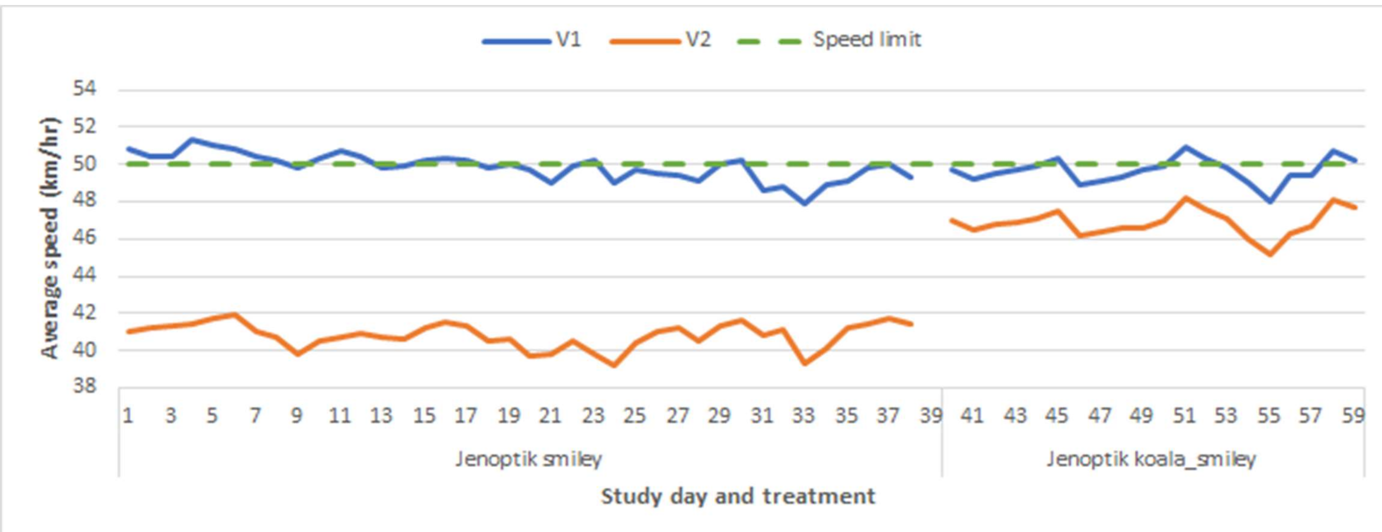



**Figure 9.** Wellington Street north average daily car speeds during the treatment 2 period when Jenoptik smiley sign 14361 was present and the treatment 3 period when Jenoptik_koala smiley sign was present 16718. The pre-treatment and treatment 1 periods, when ITS koala sign K001_01 was present, are not shown due to a lack of average daily speed data for this sign.

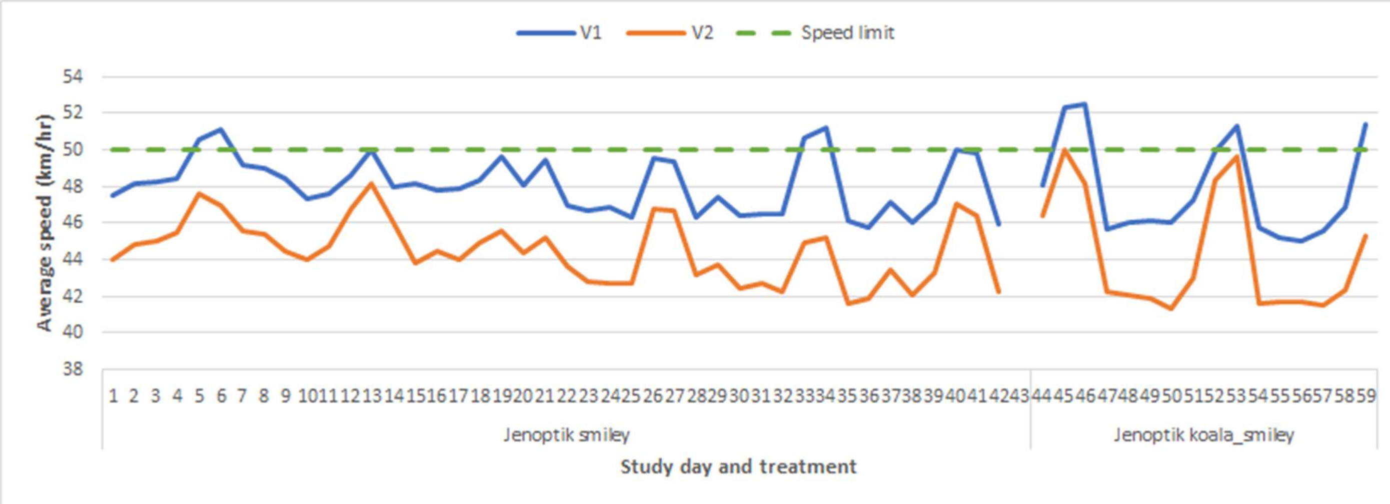



**Figure 10.** Wellington Street south average daily car speeds during the treatment 2 period when Jenoptik smiley sign 14370 was present and the treatment 3 period when Jenoptik_koala smiley sign 16720 was present. The pre-treatment and treatment 1 periods, when ITS koala sign K001_02 was present, are not shown due to a lack of average daily speed data for this sign.

As for the other locations, Jenoptik signs on Wellington Street produced relatively substantial drops from V1 to V2 average speeds, with a greater drop visible for the Jenoptik smiley sign at Wellington Street north, and great oscillation in speeds for both signs at Wellington Street south. In contrast to drivers on Sturgeon and Starkey Streets, Wellington Street drivers appeared less likely to already be traveling below the posted speed limit in terms of V1 speeds.

We then examined 'speeders' (vehicles initially travelling above a given posted speed limit), in relation to V1 and V2 average speeds (see Figures 11 through to 14).

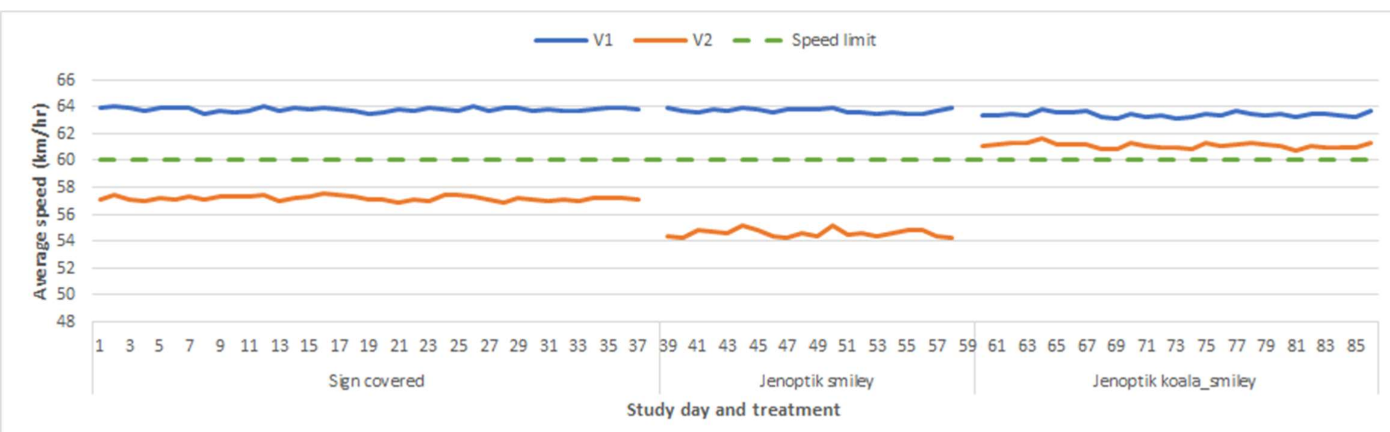



**Figure 11.** Sturgeon Street east daily average car speeds for 'speeders' during the pre-treatment period when a sign was present but covered; during the treatment 1 period when Jenoptik smiley 14361 was present; and during the treatment 2 period when Jenoptik koala_smiley 16720 was present. The treatment 3 period, when ITS koala sign K001_02 was present, is not shown due to a lack of average daily speed data for this sign.

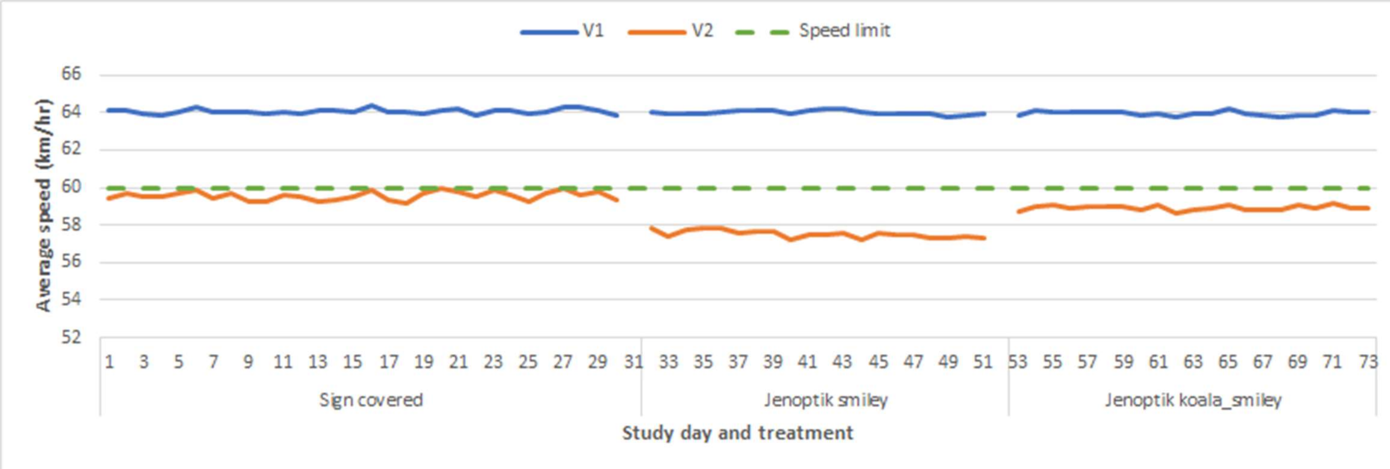



**Figure 12.** Sturgeon Street west daily average car speeds for 'speeders' during the pre-treatment period when a sign was present but covered; during the treatment 1 period when Jenoptik smiley 14370 was present; and during the treatment 2 period when Jenoptik koala_smiley 16718 was present. The treatment 3 period, when ITS koala sign K001_02 was present, is not shown due to a lack of average daily speed data for this sign.

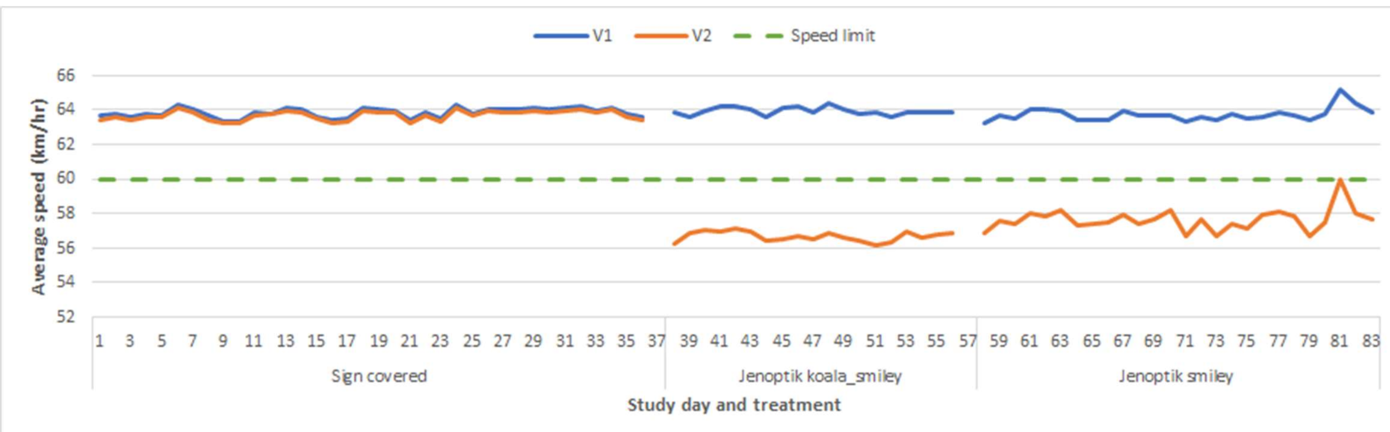



**Figure 13.** Starkey St north daily average car speeds for 'speeders' during the pre-treatment period when a sign was present but covered; during the treatment 1 period when Jenoptik koala_smiley sign 16720 was present; and during the Treatment 3 period when Jenoptik smiley sign 14361 was present. The treatment 2 period, when ITS koala sign K001_01 was present, is not shown due to a lack of average daily speed data for this sign.

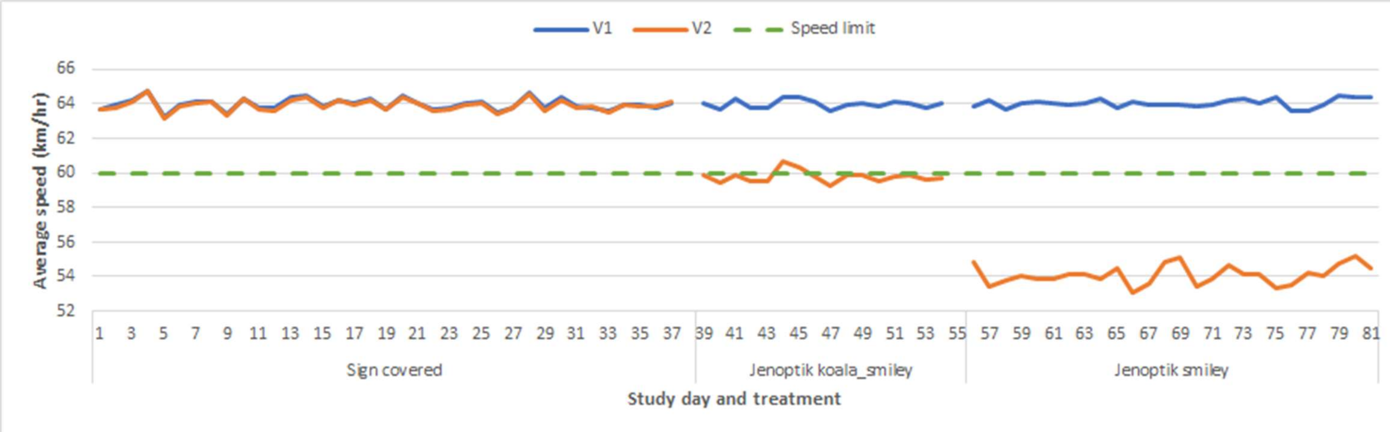



**Figure 14.** Starkey Street south daily average car speeds for 'speeders' during the pre-treatment period when a sign was present but covered; during the treatment 1 period when Jenoptik koala_smiley sign 16718 was present; and during the Treatment 3 period when Jenoptik smiley sign 14370 was present. The treatment 2 period, when ITS koala sign K001_02 was present, is not shown due to a lack of average daily speed data for this sign.

As for the overall daily average speed plots, there are clear drops between V1 and V2 speeds involving speeders for all signs and locations except those for the Jenoptik koala_smiley sign at Sturgeon Street east, where the drop was not as visible. Here, it is unclear why in that case V1 and V2 speeds are much closer than even during the pre-treatment period.

The impact of sign treatment periods appears clearest for Starkey Street signs, where pre-treatment V1 and V2 speeder averages were almost identical, compared to those in both treatment periods, with the biggest difference being for the Jenoptik smiley sign in treatment at Starkey Street south. In all treatment periods for signs on Starkey Street, averages for V2 speeds across each period were at or below posted speed limits, although on some given days it rose just above this mark for the Jenoptik koala_smiley sign at Starkey Street south.

Again, because of a lack of pre-treatment period comparative data, we separated out graphs for Wellington Street in relation to speeders (Figures 15 and 16).

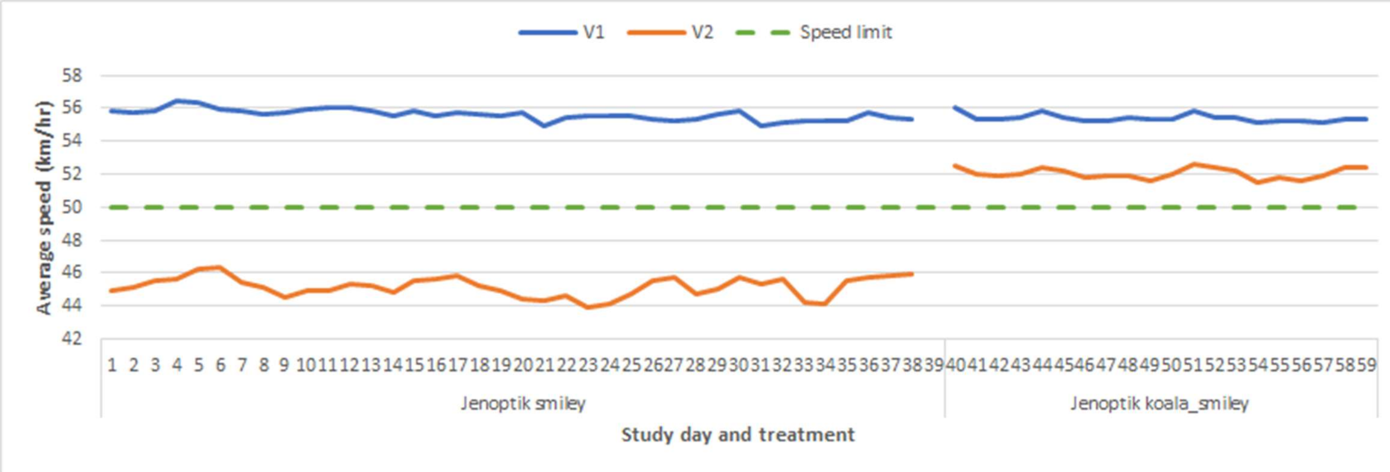



**Figure 15.** Wellington Street north daily average car speeds for 'speeders' during the treatment 2 period when Jenoptik smiley sign 14361 was present and the treatment 3 period when Jenoptik_koala smiley sign was present 16718. The pre-treatment and treatment 1 periods, when ITS koala sign K001_01 was present, are not shown due to a lack of average daily speed data for this sign.

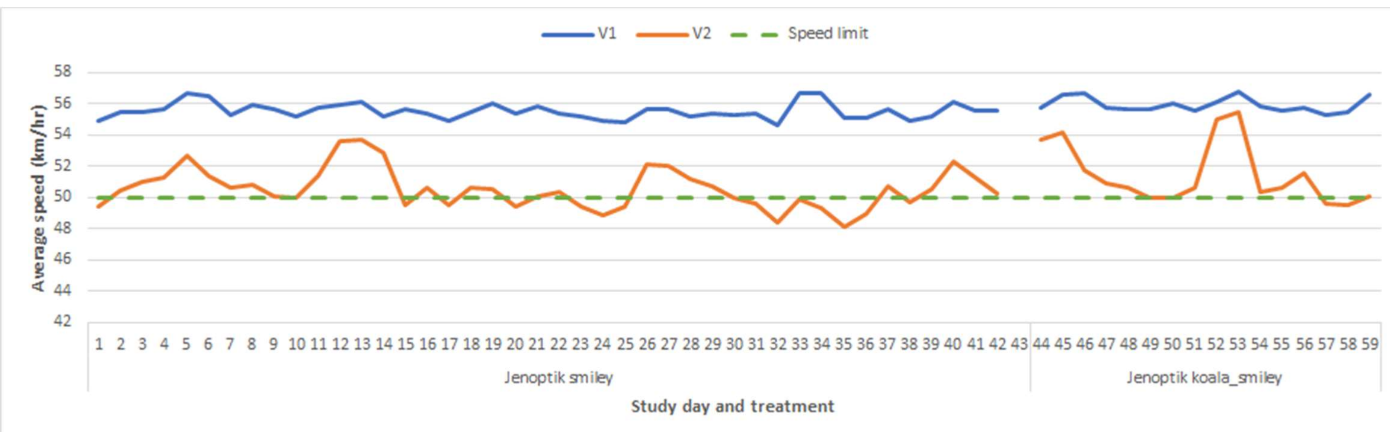



**Figure 16.** Wellington Street south daily average car speeds for 'speeders' during the treatment 2 period when Jenoptik smiley sign 14370 was present and the treatment 3 period when Jenoptik_koala smiley sign 16720 was present. The pre-treatment and treatment 1 periods, when ITS koala sign K001_02 was present, are not shown due to a lack of average daily speed data for this sign.

Similarly to the pattern for overall averages, the Jenoptik smiley sign on Wellington Street north observed a greater drop from V1 to V2 average speed for speeders than the koala_smiley sign, although at the Wellington Street south location there was little difference between the two sign types. V2 speeds were below or much closer to posted speed limits.

A very similar pattern was observed for drivers in the 85th percentile (the upper end of speed recordings), which we examined because it allowed for a more direct comparison with ITS/Artcraft signs (see Table 7).

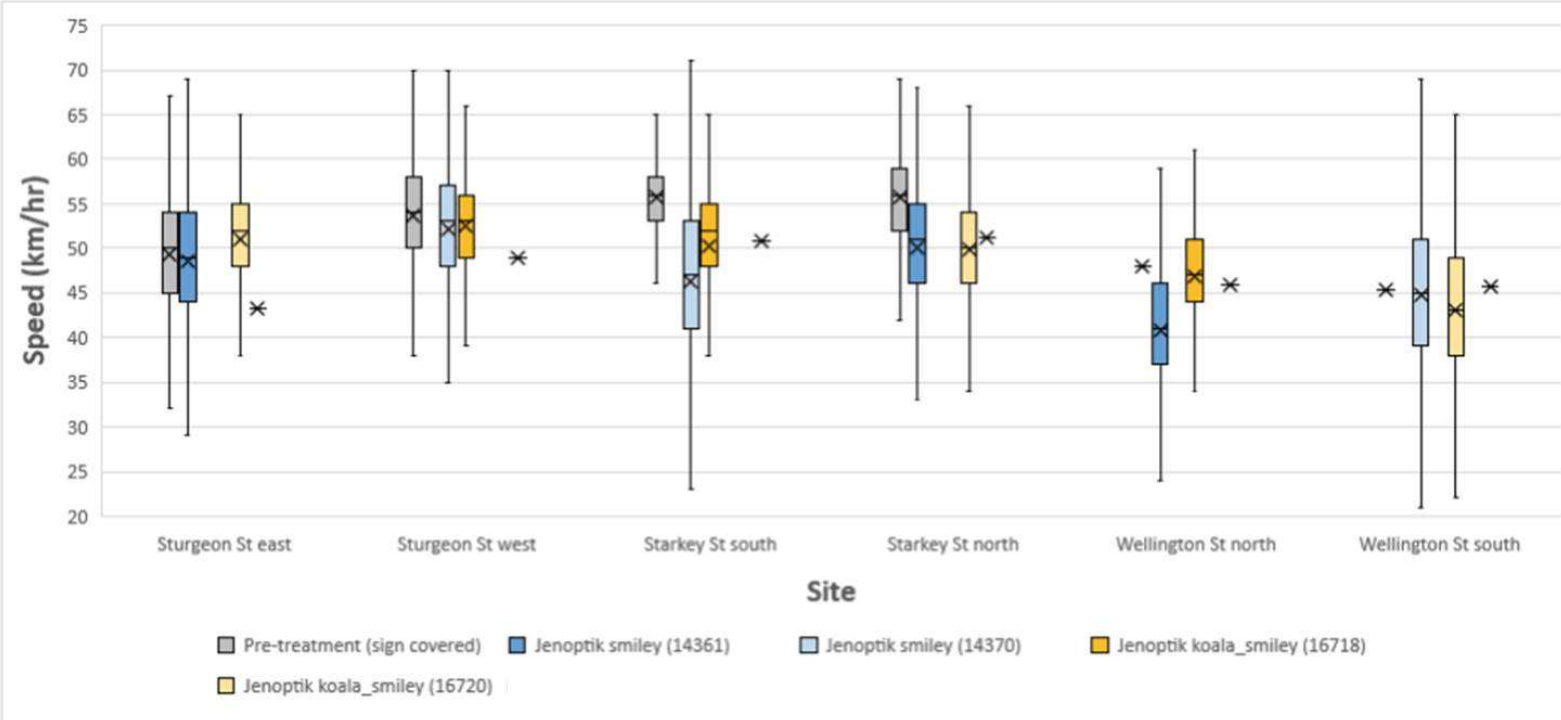
**Table 7.** 85th percentile speeds (the speed at which 85% of all drivers are recorded driving at or below) recorded by all signs during the pre-treatment period (signs covered) and three treatment periods. The 'V1' speed is recorded as the driver approaches the sign and the 'V2' speed is recorded as the driver passes the sign. The Wellington Street pre-treatment speeds were recorded by ITS koala signs, which only record one speed. Values in red represent no change or an increase in speed (or follow the link in blue immediately below to view full resolution version).

[Full resolution view of Table 7]

| | | | | | Sign type and ID | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Jenoptik smiley | | | | | | | | Jenoptik koala_smiley | | | | | | | | ITS koala | | | | |
| | | Pre-treatment period | | | 14361 | | | | 14370 | | | | 16718 | | | | 16720 | | | | K001_01 | | K001_02 | | |
| Site | Speed limit (km/hr) | V1 (km/hr) | V2 (km/hr) | % drop | V1 (km/hr) | V2 (km/hr) | % drop | % change PT V2 to V2 | V1 (km/hr) | V2 (km/hr) | % drop | % change PT V2 to V2 | V1 (km/hr) | V2 (km/hr) | % drop | % change PT V2 to V2 | V1 (km/hr) | V2 (km/hr) | % drop | % change PT V2 to V2 | V2 (km/hr) | % change PT V2 to V2 | V2 (km/hr) | % change PT V2 to V2 | Best performing sign type for each site |
| Sturgeon St east | 60 | 59 | 56 | -5.08 | 59 | 56 | -5.08 | 0.00 | | | | | | | | | 59 | 57 | -3.39 | 1.79 | 54.4 | -2.86 | | | ITS koala |
| Sturgeon St west | 60 | 62 | 60 | -3.23 | | | | | 62 | 59 | -4.84 | -1.67 | 61 | 58 | -4.92 | -3.33 | | | | | | | 57.80 | -3.67 | ITS koala |
| Starkey St south | 60 | 60 | 60 | 0 | | | | | 60 | 56 | -6.67 | -6.67 | 60 | 57 | -5.00 | -5.00 | | | | | | | 58.30 | -2.83 | Jenoptik smiley |
| Starkey St north | 60 | 61 | 61 | 0 | 60 | 57 | -5.00 | -6.56 | | | | | | | | | 61 | 56 | -8.20 | -8.20 | 58.4 | -4.26 | | | Jenoptik koala_smiley |
| Wellington St north | 50 | | 56.2 | | 57 | 49 | -14.04 | -12.81 | | | | | 56 | 53 | -5.36 | -5.69 | | | | | 54.4 | -3.20 | | | Jenoptik smiley |
| Wellington St south | 50 | | 54.8 | | | | | | 56 | 53 | -5.36 | -3.28 | | | | | 55 | 52 | -5.45 | -5.11 | | | 54.40 | -0.73 | Jenoptik koala_smiley |

Looking at Table 7, all but two cases (both at the same location at Sturgeon Street east) resulted in a decrease in 85th percentile speed in all treatment periods compared to the pre-treatment period, with percentage drop ranging from 0.730-12.81%.

Finally, as a means of presenting all results together in one visualisation, Figure 17 is a box and whisker plot of average (mean and median) speeds on each street for each sign during the pre-treatment and treatment periods.




Higher resolution version of plot

**Figure 17.** The distribution of speeds during the pre-treatment and all three treatment periods for all signs. For the Jenoptik signs the average speeds are calculated from the V2 speed, as the driver is passing the sign. The box and whiskers represent the mean, median, interquartile range, maximum and minimum speeds. For the ITS signs only the mean and median are shown as a bare ⋇ symbol. Means correspond with the 'x' element and medians with the '-' (dash) element of the symbol (or follow the link in blue above to view full resolution version)

Whilst this generally shows that treatment period average speeds were lower than pre-treatment average speeds (with the exception of Jenoptik koala_smiley sign 16720 on Sturgeon St east and ITS koala sign K001_02 at Wellington Street south), there is considerable overlap of boxes in most cases. Results for Starkey Street north and south seem to show the least amount of overlap in this regard, but as was demonstrated previously, there is also notable variability within given signs at given locations, including on Starkey Street, and especially for Jenoptik smiley sign 14370.

# 4. Discussion

The dynamic signs appear to have successfully encouraged most drivers to reduce their speed during treatment periods, for example, in comparison to average pre-treatment speeds. The direct impact of the signs on vehicle speed is particularly apparent in relation to the consistent drop in average speed after vehicles passed signs, in comparison to average speeds before passing signs. It is also worth noting that encouragingly, most drivers were already travelling below posted speed limits as recorded during the pre-treatment period, and in some cases, well below. This makes the potential benefits of dynamic signs even more apparent, as they appeared to consistently encourage drivers already travelling under the speed limit to slow down even further.

Additionally encouraging is that in many cases, 'speeders' (vehicles traveling over the speed limit), and those in the 85th percentile, were also recorded to have reduced their speeds in apparent response to signs. This often resulted in them subsequently travelling below posted speed limits, which is good news not just potentially for koalas, but for road safety in Ormiston more generally.

Jenoptik signs provided the clearest evidence of the direct impact of signs because both before and after speeds were available for comparison. This was highlighted by Sullivan et al. (2013) as a way for potentially providing the clearest picture of in-situ signage effects. This differential measurement capability alone makes the Jenoptik models a compelling choice for future research. We were reliant upon broader comparisons for the ITS/Artcraft signs, but these also suggested a consistent reduction in average speed between the pre-treatment and treatment periods in most cases, as well as a reduction in the number of overall speeders and their average speeds. It is possible, for instance, that the flashing lights the ITS/Artcraft signs feature, closely resemble those on other familiar signage in the area, such as school zone signs, and drivers therefore responded as they might in such zones.

Results suggest that both flashing lights and LED display panels are capable of alerting drivers and encouraging them to reduce speed, although they may do so in slightly different ways. Signs with flashing lights (in the current study they were only used on the ITS/Artcraft models) are a commonly utilised approach to warning drivers about hazards. In the current application, limiting their operation to alerting drivers exceeding a speed threshold such as the posted speed limit is likely to act similarly as a warning, and as a result, for drivers to slow. A potential limitation of this approach is that it is binary. In other words, drivers either receive a warning if they are traveling above a set speed, or otherwise receive no feedback or encouragement. The variable display options available using LED panels (as used in both models of the Jenoptik signs) provide additional steps to incrementally encourage speed reductions using reinforcement. In principle, this adds additional sophistication to speed reduction programs, as it offers a greater opportunity to encourage drivers to slow down at multiple speed thresholds, because they receive different messages (presumed to be reinforcing) at different thresholds, just as Bond and Jones (2013) suggested. It is however unclear whether this sophistication actually results in more consistently beneficial results, making it worthy of further investigation.

In the methodology section we outlined several limitations and issues that proved challenging to overcome in terms of more accurately determining sign performance. Whilst signs consistently recorded drops in speed in almost all cases, the variability within and between signs makes strong conclusions impossible. A part of the 'problem' is in essence, a good problem to have: drivers were already often travelling well below the speed limit on the trial streets before signs were displayed. In order to tease out exactly what role signs and messaging are playing however, some revisements of experimental design are worth considering for future investigations. One consideration is to maintain one or more 'control' roads throughout an entire study period. This would be of great benefit in examining seasonal and holiday period effects, as well as any other potential sources of speed variation in the absence of treatment signs and messaging. A second consideration is increased replication in different areas, and ideally, in areas where independence between sign measurements is more likely. Additionally, being able to test signs, or sign radar equipment side-by-side would be advantageous, as it would allow for a comparison in measurements in exactly the same experimental situations.

In the current study, the results from Starkey Street might be considered to best represent a clearer picture of the impact of signs, because the site was devoid of some (although not all) of the confounding issues on the other two streets (e.g. roundabouts on Sturgeon Street; more limited pre-treatment data from the ITS/Artcraft signs on Wellington Street). We are also cautious about any interpretation of the ITS/Artcraft signs more generally because of lower than expected vehicle counts in several cases. On Starkey Street, both of the Jenoptik sign models (the 'smiley' and the 'koala_smiley') were the best performers, and interestingly each model was better than the other depending on the location on the street. It is not clear why this would be the case and it differs from the results of Blacker et al. (2019), who found the koala-specific model to consistently outperform the more generic model. It is an especially interesting result given that it would be expected that a relatively high number of the same drivers on the street would have encountered both signs.

Another difference between the current study and that of Blacker et al. (2019) is the length of time over which data were collected, which was considerably longer in the current study. A very promising result in this regard is that it did not appear habituation had occurred, or was occurring, although the time spans of exposure to each particular sign in each location was relatively brief. Habituation as a process may occur over a longer period of time than either the current study or that of Blacker et al. (2019) occurred, and this remains one of the most important variables that is yet to be properly investigated.

Neither are we able to directly relate the performance of signs with the measure of greatest importance in this application: koala strikes. It is certainly promising that, to our knowledge, no koalas have been struck on any of the trial streets since the study was initiated. It is also very encouraging that residents have reported a strong awareness of signs in a recent parallel study (Pang et al. 2020). This potentially highlights the importance of complementary education and awareness programs in enhancing and maintaining the beneficial impacts of signs, because drivers have a more in-depth knowledge of the purpose of signs, and comprehensively support the initiative behind it. It may also be a critical element in helping to offset or prevent habituation, but only further study and replication can properly determine this. There may be an opportunity with further parallel research to survey drivers about any koala sightings on or near roads in the area, including any roads outfitted with signage. Other research programs (e.g. tracking studies) could also provide supplementary information about koala movement near roads, including those with signs. Improving our understanding of the relationship between vehicle speed and driver vigilance remains an important knowledge gap, which again, may be partly bridged through surveys. In turn, our understanding of strike events, koala road crossing frequency and dynamics, and driver awareness is likely to considerably improve.

In terms of signs and messaging, all three signs appear to offer benefits in terms of encouraging drivers to reduce their speed, suggesting that different aspects of the signs may have appealed to different drivers. The clearest differences between sign features was that the Jenoptik smiley signs had no koala-specific information, and the ITS/Artcraft signs had flashing lights. It might therefore be worth considering ‘modularising’ sign components, using the generic Jenoptik smiley sign as a base. For instance, the ability to add flashing lights similar to the ITS/Artcraft flashers to the tops of signs may further enhance their visibility to drivers that are driving over a target speed threshold. A removable panel containing the koala-specific information would mean that any Jenoptik smiley sign could effectively be outfitted to be a koala-specific sign. This could allow for greater flexibility, for example signs could be rotated to areas where koala strike is a minimal concern, but other speed or traffic hazards are present. Conversely, in areas of great concern (e.g. high numbers of recent strike events) signs with as many features as possible could provide added incentives for as many drivers as possible.

Figure 18 provides a concept of such a design, taking the flashing lights and koala information panel from an ITS/Artcraft sign, and combining them with the generic Jenoptik smiley sign. Each element is principally ‘standalone’, such that it could be added or removed as necessary. Additional considerations such as the colouration of text (e.g. which colours do drivers prefer or are more visible) could be explored via surveys or small pilot-level investigations.


**Figure 18.** A conceptual image of a koala sign that combines features from all three of the signs trialed during the current study phase.

# 5. Recommendations

1. Extend the study so that habituation, a key factor in the long-term performance of signs can be properly investigated.
2. Expand the study to include more sites, which will improve replication, and may in turn help ascertain a clearer picture of which sign model and features consistently produce the most beneficial reductions in vehicle speed. This includes the use of true control roads if at all possible (roads where, for example, vehicle speeds in relation to passive/generic wildlife signs are consistently measured over an entire study period).
3. Conduct a short study with signs/sign radars side-by-side at the same location to examine any differences in individual data collection performance and potentially allow for better calibration.
4. Consider amalgamating features from all three sign types/models as each may appeal to different sets of drivers.
5. Draw data from a variety of sources in an effort to explore any relationships between community engagement programs, koala movement and ecology, sign presence/absence and strike events.

# 6. Conclusion

All three sign models trialed during this study appeared to consistently produce reductions in average vehicle speed. Rather than there being a single, standout sign type/model, different signs performed better or worse depending on experimental period and site (location). Interestingly, different models even performed better or worse on the same streets, where a reasonably high proportion of the same drivers would be expected to be encountering each sign. Thus, there was no sign type/model that clearly outperformed the other models in every context. However, both the Jenoptik models did appear to more consistently record larger volumes of vehicles throughout the study period in any given location, suggesting their results may be more reliably comparable. In turn, some concerns arose over the lower than expected number of vehicles recorded on the ITS/Artcraft signs, particularly sign K1001_01. Jenoptik models also provided the clearest indication of sign performance because they allowed for a comparison of average speeds before and after drivers encountered signs. Encouragingly, this comparison universally demonstrated that most drivers reduced speeds when encountering signs. Further, given that there were such clear and consistent drops in average and upper speeds after drivers had passed signs, this may even represent, albeit it putative evidence of increased vigilance, as drivers noticing signs and responding appropriately is at least an indication of spatial awareness. Equally commendably, most drivers in Ormiston were already driving below the posted speed limit even before encountering signs. And although it is impossible to directly relate sign performance to koala strike events, no koalas appear to have been struck on trial streets during the study, which itself is promising. Overall, dynamic, interactive signs may therefore represent an important, additional strategy in reducing koala strike events and warrant greater investigation.

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# Appendices

## Appendix 1 – Technical and data issues

- Numerous periods of missing time were found in all Jenoptik sign datasets, where no cars were recorded. These missing time periods range from less than an hour to more than 24 hours (and in total represent around a 3% loss of the raw data for this study), which suggests a technical issue with the signs rather than an absence of cars. Wherever a particular date had a high percentage of time missing and the remaining data created an anomalous spike or dip in average speeds, these dates were removed from the datasets
- The Jenoptik signs record two speeds for each car: V1 is the initial car speed, and V2 is the car speed after the driver has (presumably) seen the sign. In many cases (around 46% of the raw data collected during treatment periods) the V1 was recorded but the V2 was not recorded, so any records without V2 speeds were removed to prevent the data being skewed by the higher proportion of V1 speeds (see Appendix 2)
- The two Jenoptik smiley signs on Sturgeon Street (14361, 14370) showed a drop in speed between V1 and V2 during the control period when the signs were covered, where we would expect to see no change between V1 and V2. We think this is due to traffic slowing as they approached roundabouts. Subsequently, when comparing average speeds for Sturgeon Street during treatment periods to this pre-treatment period, the comparisons were made between the V2 speeds to account for the already slowing traffic
- Jenoptik koala_smiley sign 16720 on Starkey Street north showed a sharp increase in average speeds on 31/10/2019 due to only around 38min of data being collected on this day and one car recorded at 107km/hr during this time, so data from this date were removed from this dataset
- On 16/12/2019 the minimum speed threshold on all Jenoptik signs was changed from 20km/hr to 19km/hr to try to prevent power down. A decrease in average daily speeds was noted in Jenoptik smiley sign 14361 at Sturgeon Street east from this date so data prior to 17/12/2019 were removed from this dataset
- Jenoptik smiley sign 14370 on Sturgeon Street west recorded many anomalous dips in average speeds in the last week of the pre-treatment period and the first week of the first treatment period. The cause is unknown, but these data were removed as anomalies from this dataset
- Jenoptik koala_smiley signs 16718 and 16720 at Starkey Street appeared not to be functioning correctly during the first half of the first treatment period, up until 16/12/19. There was no difference between V1 and V2 speeds (like a pre-treatment period when signs are covered) until roughly halfway through the treatment when the V1 and V2 speeds were consistently different for the remainder of the period. In this case the overlapping V1 and V2 data in the first half of these datasets were removed. For sign 16718 there were no data recorded on 16/12/19 (the date that the minimum speed thresholds were changed on all Jenoptik signs), then anomalously low speeds were

recorded on both signs from 17/12/2019 for several days. The cause of the low speeds is unknown and these data were also removed from this dataset

- Jenoptik koala_smiley sign 16718 at Starkey Street south recorded two days of data in a row with the same date (31/12/2019). Since the car speed data were not identical between these two dates it was assumed that the second day was actually 1/1/2020 so this day's data was retained in the dataset. In case the following dates were all out by one day as a result, any data were removed where they may have been recorded during sign rotation days at the beginning or end of treatment periods
- On 15/01/2020 incorrect 50km/hr posted signs on Starkey Street ITS koala signs were taken down. These signs had displayed the wrong speed limit since the rotation (6/01/2020). On 16/01/2020 at approximately 10am the correct 60km/hr signs were placed on these signs. The data on the relevant dates were removed from the dataset
- Jenoptik koala_smiley sign 16720 at Sturgeon St east had only four records on 4/2/2020, and only one of those rows had a V2, so data from this date were removed from the dataset
- Jenoptik smiley sign 14361 at Wellington Street north had many periods of missing time where no data were recorded between 4/2/2020 and 6/2/2020. The sign was reported to have rotated at some point prior to 6/2/2020 so this is most likely the cause. The data that were recorded were mostly missing the V2 speed (only the V1 speed was recorded) and so were removed. The only remaining data recorded on 6/2 was four records between 9-14 km/hr. These dates were removed from this dataset
- Jenoptik koala_smiley sign 16720 had a big period of missing time where no data were recorded between 16/2/2020 23:55 and 21/2/2020 7:03
- Jenoptik koala_smiley sign 16718 at Wellington Street north recorded many extremely low speeds on 9/3/2020 (e.g. 8-11km/hr), due to an unknown cause, resulting in a sharp decrease in average daily speeds so these data were removed from this dataset
- Jenoptik koala_smiley sign 16720 at Wellington Street south recorded a large drop in average daily speeds from 8/3/2020, due to an unknown cause. The sign was reported to have been facing the wrong way for some time on 20/3/2020 so this is most likely the cause. Data from 8/3/2020 onwards were therefore removed from this dataset.

# Appendix 2 – Data loss summary

**Appendix Table 1.** The number of observations recorded by each sign in the raw datasets; the total number of observations removed; the number of observations removed due to Jenoptik signs failing to record a V2; the number of observations removed due to other anomalies (including signs being moved or sign settings being changed); the number of remaining observations used for analyses; and the percentage of raw data lost due to removals.

| Sign ID | No. of obs. in raw data | No. of obs. removed | Removals due to blank V2s | Removals due to other anomalies | No. of obs. used | % of raw data lost |
|---|---|---|---|---|---|---|
| Jenoptik smiley 14361 | 1,405,762 | 778,588 | 645,978 | 132,610 | 627,174 | 55.39 |
| Jenoptik smiley 14370 | 1,393,246 | 850,393 | 698,385 | 152,008 | 542,853 | 61.04 |
| Jenoptik koala_smiley 16718 | 888,154 | 581,578 | 402,350 | 179,228 | 306,576 | 65.48 |
| Jenoptik koala_smiley 16720 | 692,362 | 388,634 | 303,124 | 85,510 | 303,728 | 56.13 |
| ITS koala K001_01 | 11,476 | 408 | | 408 | 11,068 | 3.56 |
| ITS koala K001_02 | 51,415 | 1,234 | | 1,234 | 50,181 | 2.40 |
| **Total** | 4,442,415 | 2,600,835 | 2,049,837 | 550,998 | 1,841,580 | 58.55 |