On-road evaluation of the driving performance impact of digital billboards at intersections

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1 BACKGROUND

Driver distraction occurs when a driver's attention is diverted away from the task of driving and toward another activity or object, often to the detriment of driving performance (Regan, Hallet & Gordon, 2011). Because advertising devices such as digital billboards are designed to attract attention, they have the potential to cause driver distraction by diverting the driver's attention away from the driving task, potentially compromising safety. Driving environments which are cognitively demanding, such as intersections and high traffic areas, may increase this safety risk significantly.

Not all locations and billboard designs are likely to be equally risky and indeed some are likely to be acceptable from a safety perspective. For this reason, it is important to have an evidence-based approach to assessing the road safety risk associated with digital billboard installations and proposals. While AP-R420-13 (Austroads, 2013) sets out the key principles that influence distraction risk, the research literature currently is not sufficiently developed to allow definitive conclusions about the quantitative impact on driving performance of particular billboard installations[1].

To gain some insight in to the impact on driving performance of typical digital billboard installations, the Outdoor Media Association (OMA) engaged ARRB to conduct an evaluation of the impact on driving performance of new digital billboards installations at two locations: 1) Phillip St / Dawson Hwy intersection in Gladstone, Queensland (see Figure 1.1), and 2) Elkhorn Ave / Surfer's Paradise Blvd in Surfer's Paradise, Queensland (see Figure 1.2). This evaluation took the form of a video survey of vehicle control with the aim of assessing the impact of the digital billboard when lit.

[1] A comprehensive review of the extant literature was not part of the scope of this project. The reader is referred to AP-R420-13 for a review of relevant material.

Figure 1.1: Proposed digital billboard location on the corner of Philip Street and Dawson Highway

Figure 1.2: Proposed digital billboard location on the corner of Elkhorn Ave and Surfer's Paradise Blvd

2 METHODOLOGY

For both sites, video data of vehicle movement approaching the cameras was collected continuously. The resultant video was coded to extract relevant vehicle movements for the periods 6am – 9am, 3pm – 6pm and 8pm – 11pm. These times were chosen to capture both free flow and congested traffic conditions at the site. For both sites, vehicle movements were coded for all vehicles as they passed through the intersection.

During the course of the post-installation evaluations, the digital billboards were loaded with typical content and static images were displayed.

This video data in these periods were coded to extract:

- Lane drift (number of instances of drifting outside of the lane in each time period)
- ‘Stopping-over-the-line’ (number of instances of stopping over the stop line in each time period)
- Incidents (number of instances in each time period)

Lane drift and stopping over the line were treated as binary variables – either a vehicle crossed the relevant white line, or it didn’t. This approach is analytically unambiguous and was successful at detecting significant effects in a previous study (unpublished, for Main Roads WA).

A number of previous studies have shown that lane drift increases in the presence of visual distraction (Kountouriotis & Merat, 2016; Liang & Lee, 2010) and also, specifically, in the presence of a digital billboard (Schieber et al., 2014).

In addition, both lane drift and stopping over the line measures have good face validity for the current application as they are plausible precursors to the kinds of crashes likely to occur when attention is inappropriately focussed in a multiple lane, signal controlled intersection environment; that is, sideswipe and rear end. Furthermore, increases in stopping over the line behaviour are likely to signal an increased risk of red light running with the concomitant increase in risk of high severity right angle crash types. However, because these measures are not validated, in such a way that the quantitative impact on crash risk can be predicted at this point in time, this report talks about these as driver performance metrics rather than safety metrics.

2.1 Gladstone Site

The design of the evaluation was a before-after study of the Philip St / Dawson Hwy traffic light-controlled intersection, with a matched control site (Far St / Dawson Hwy traffic light-controlled intersection). Data was collected for a 1-week period before the billboard was lit and continued for 3 weeks following activation of the digital billboard. The digital billboard was lit on the 11th of March.

The approach to the proposed billboard location consists of a three-lane traffic light-controlled intersection with a 60km/h posted speed limit and is straight and level and in direct line-of-sight to the sign face. The sign is approximately 125m away from the stop line. Figure 2.1 and Figure 2.2 show the data collection areas for both sites.

Table 2.1 shows the data collection timing at the two sites.

Table 2.1: Gladstone data collection timing

	Data Collection 1 (22/01 – 27/01)	Data Collection 2 (12/03 – 17/03)	Data Collection 3 (19/03 – 24/03)	Data Collection 4 (26/03 – 31/03)
Philip St / Dawson Hwy Intersection	No billboard	Billboard illuminated – 24 sec dwell time	Billboard illuminated – 16 sec dwell time	Billboard illuminated – 8 sec dwell time
Far St / Dawson Hwy Intersection	No billboard	No billboard	No billboard	No billboard

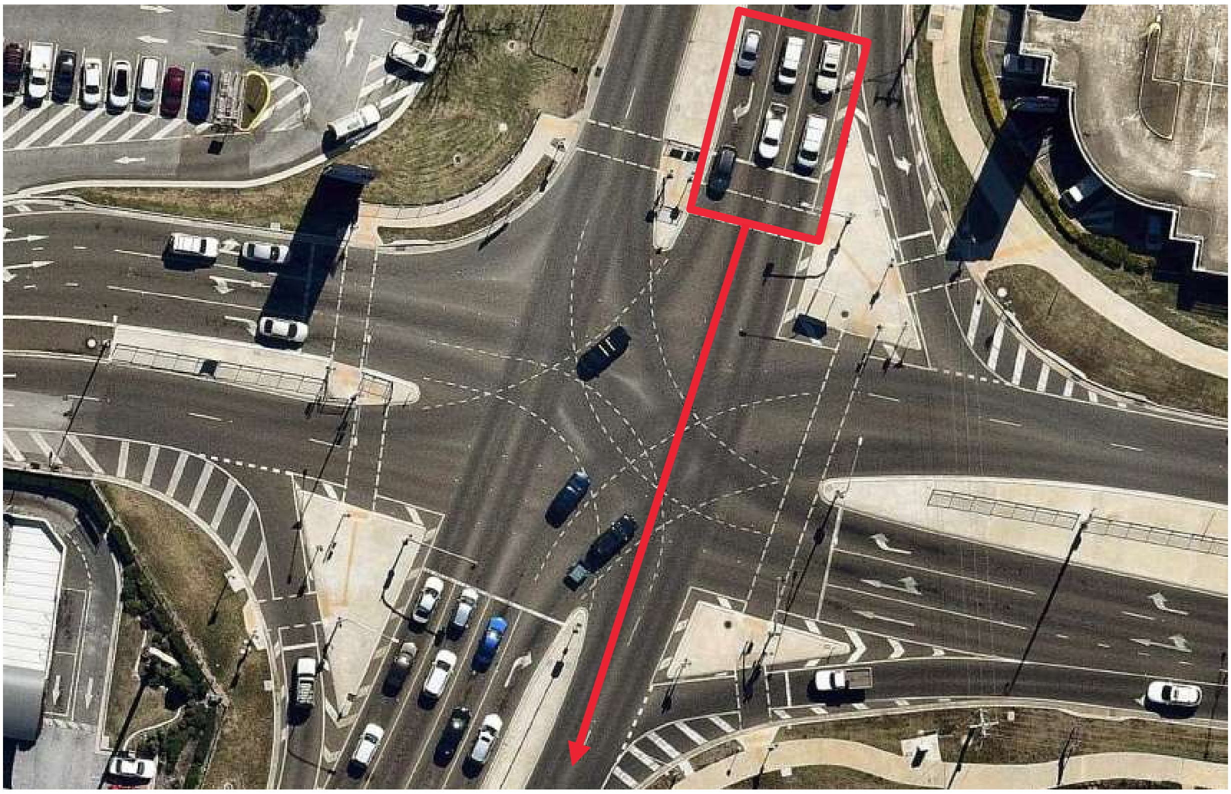

Figure 2.1: Philip St / Dawson Hwy evaluation site intersection

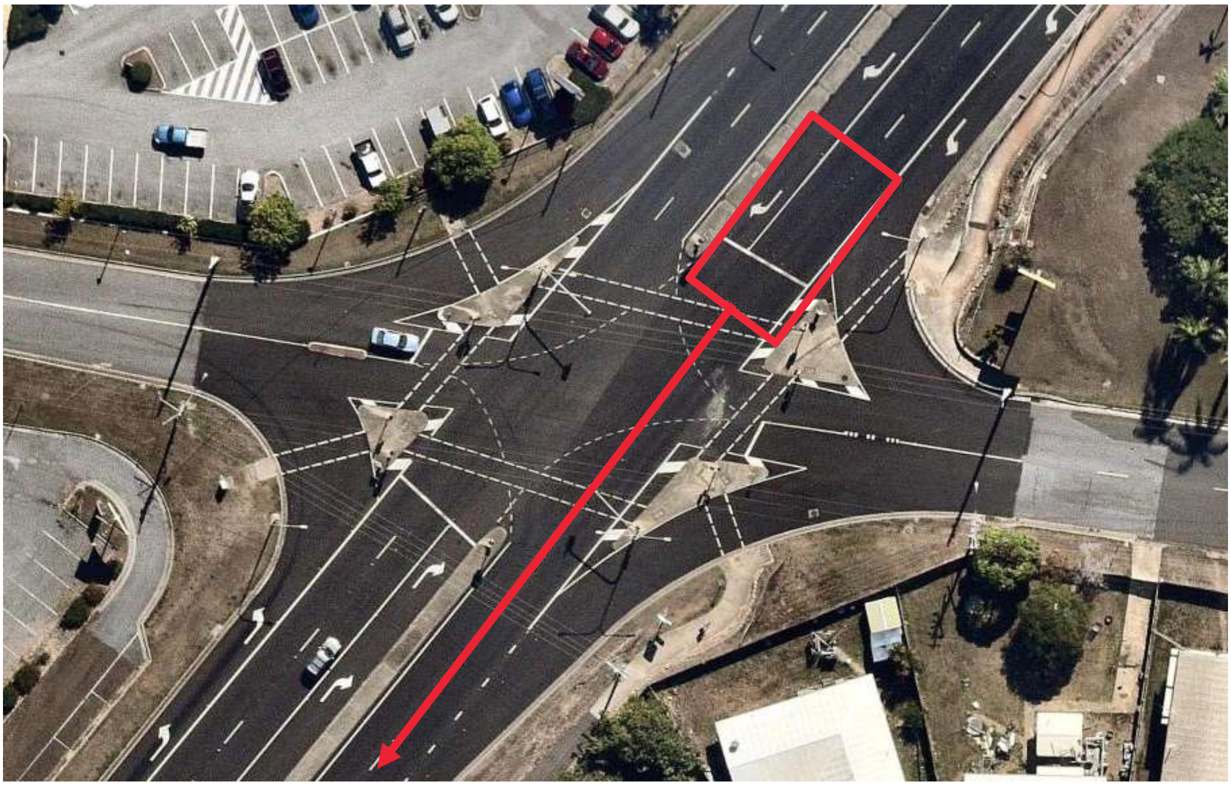

Figure 2.2: Far St / Dawson Hwy comparison site intersection

Figure 2.3: Proposed billboard location at the intersection of Phillip St and Dawson Hwy

Figure 2.4: Far St / Dawson Hwy comparison site street view

2.2 Surfer's Paradise Site

The design of the second evaluation was a before-after study of the Elkhorn Ave / Surfer's Paradise Blvd traffic light-controlled intersection, with a matched control site (Cavill Ave / Surfer's Paradise Blvd traffic light-controlled intersection). Data was collected for a 1-week period before the billboard was lit and continued for 3 weeks following activation of the digital billboard. The digital billboard was lit on the 2nd of March.

The approach to the proposed billboard location consists of a two-lane traffic light-controlled intersection with a 40km/h posted speed limit. The sign is approximately 30m away from the stop line and is positioned slightly up and to the left (Northen leg), and right (Western leg), of the driver's line-of-sight. Figure 2.6 and Figure 2.7 show an aerial view of the Elkhorn Ave and Cavill Ave sites, respectively. Figure 2.8, 2.9, 2.10 and 2.11 show street views of the northern and western legs at both Elkhorn Ave and Cavill Ave, respectively.

Table 2.2 shows the data collection timing at the two sites.

Table 2.2: Surfer's Paradise data collection timing

	Data Collection 1 (24/01 – 29/01)	Data Collection 2 (3/03 – 9/03)	Data Collection 3 (10/03 – 16/03)	Data Collection 4 (19/03 – 24/03)
Elkhorn Ave / Surfer's Paradise Blvd	No billboard	Billboard illuminated – 30 sec dwell time	Billboard illuminated – 20 sec dwell time	Billboard illuminated – 10 sec dwell time
Cavill Ave / Surfer's Paradise Blvd	No billboard	No billboard	No billboard	No billboard

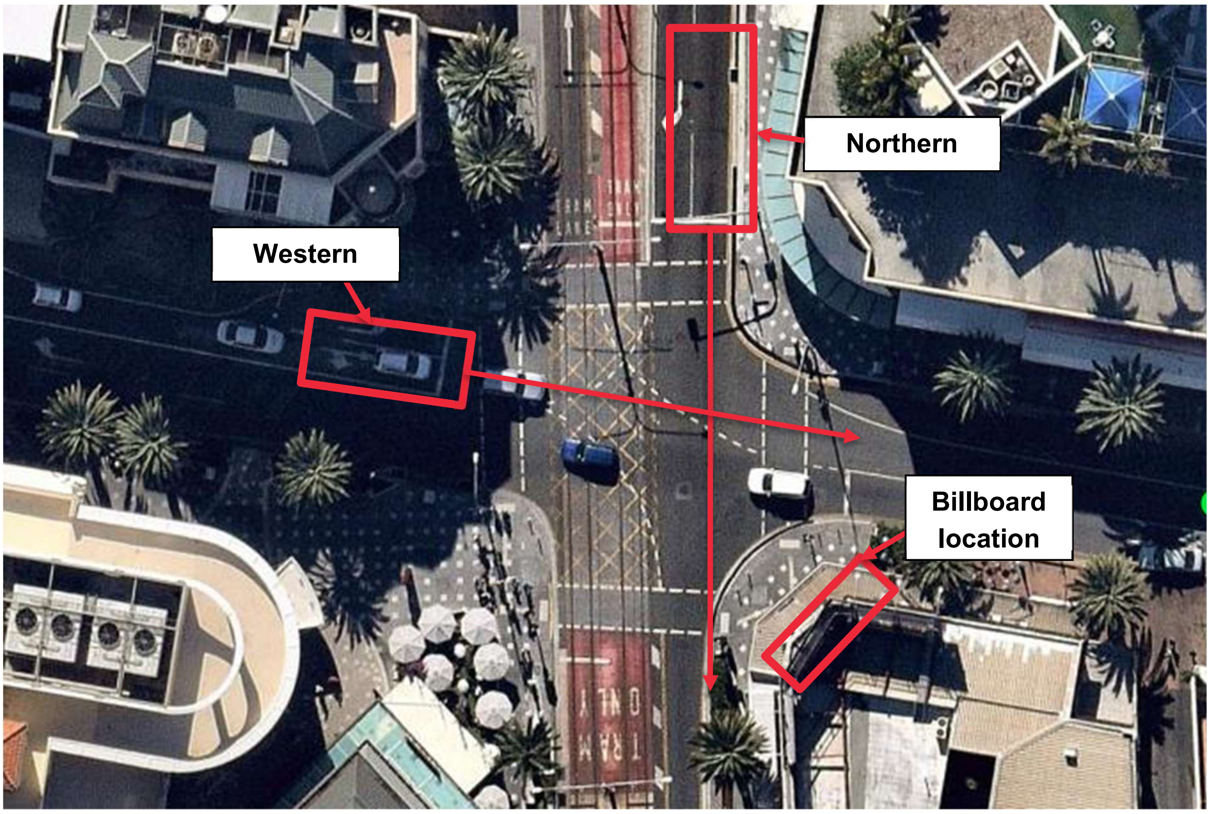

Figure 2.5: Proposed digital billboard location on the corner of Elkhorn Ave and Surfer's Paradise Blvd

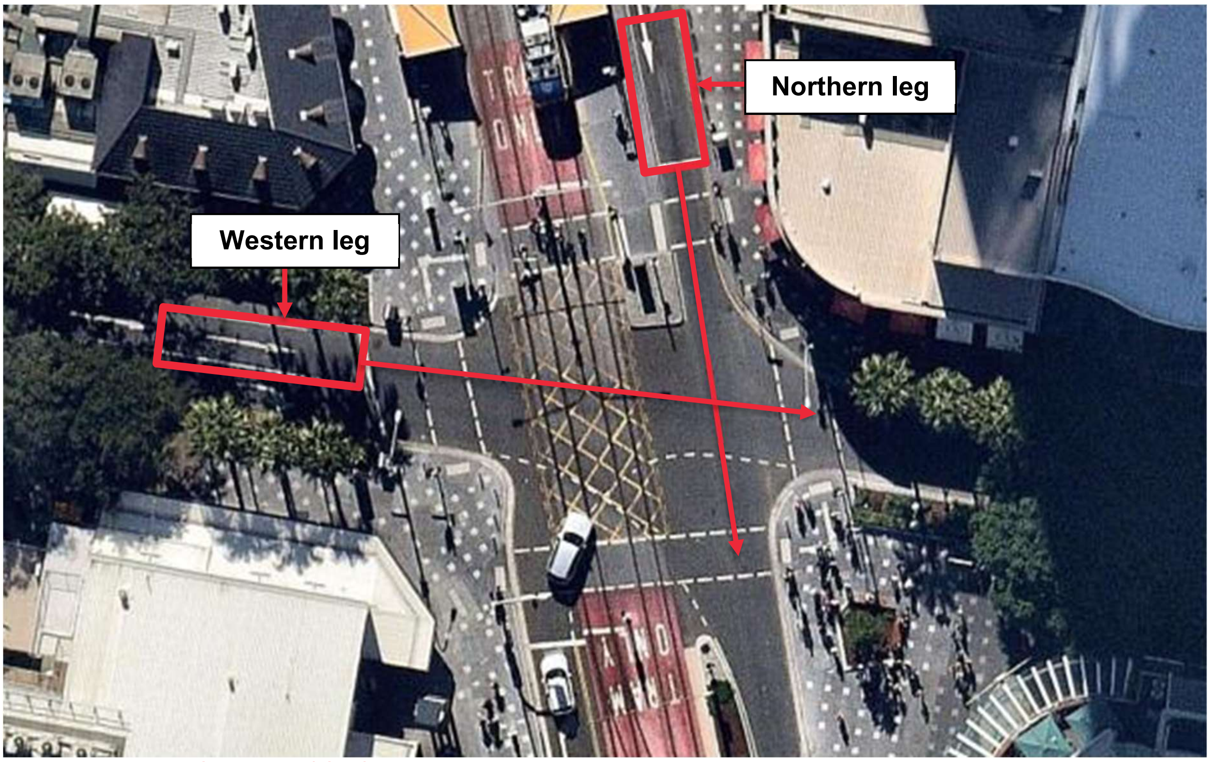

Figure 2.6: Cavill Ave / Surfer's Paradise Blvd comparison site intersection

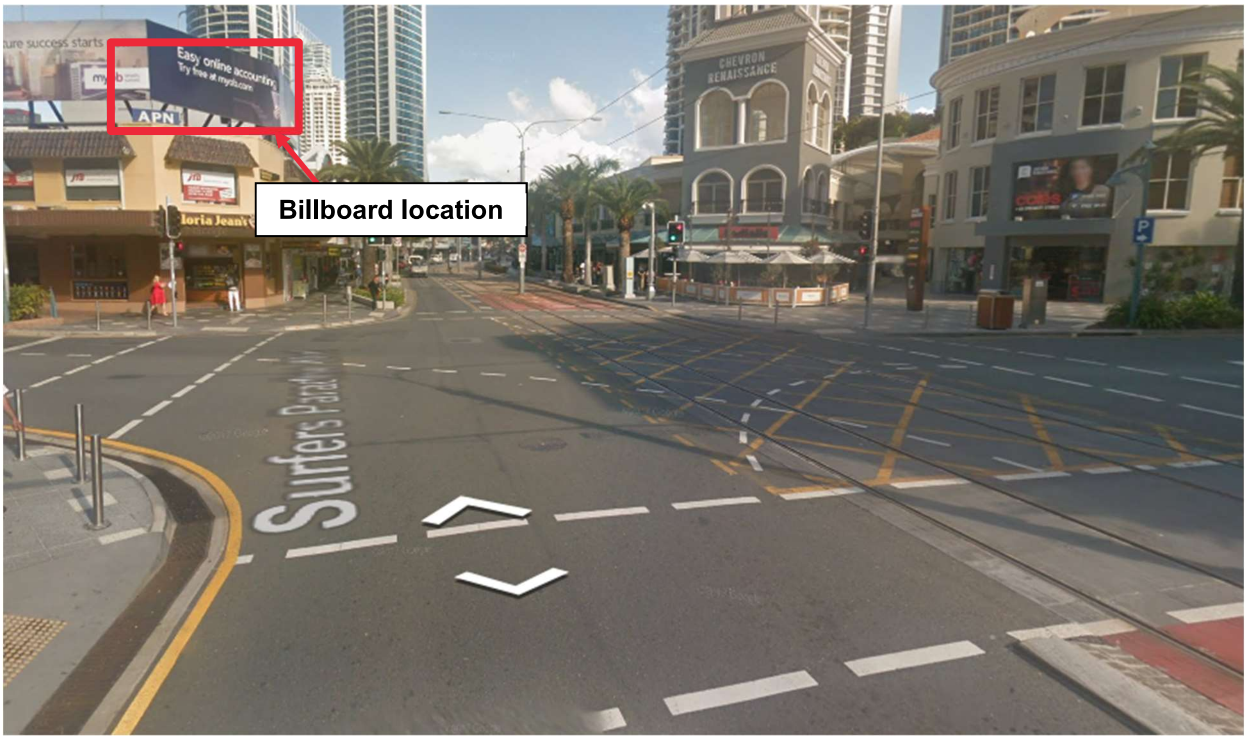

Figure 2.7: Elkhorn Ave northern leg street view

Figure 2.8: Elkhorn Ave western leg street view

Figure 2.9: Cavill Ave northern leg street view

Figure 2.10: Cavill Ave western leg street view

3 RESULTS

The video data was examined by trained raters. Each of the periods (6am – 9am, 3pm – 6pm and 8pm – 11pm) was divided in to 15-minute blocks and the number of instances of lane drift and 'stopping over the line' were counted. In addition, the number of incidents (defined as a crash or running a red light) in the same 15-minute windows were recorded.

3.1 Gladstone Site

To assess whether there was any evidence of a negative impact from the digital billboard being lit, 'before' and 'after' change scores were subjected to a paired samples *t*-test for each dwell time. The main comparison of interest was any difference between the two sites (Phillip St and Far St) in lane drift and instances of stopping over the line, following activation of the digital billboard. Significance levels were evaluated at a Bonferroni-corrected alpha level of .017 (.05 x 3 dwell time comparisons).

There were no incidents in any of the time periods examined.

3.1.1 Lane drift

The mean lane drift instances for the two sites before and after the digital billboard was switched on are shown in Table 3.1.

Table 3.1: Lane drift (mean number of instances)

Site	Period			
	Before	24 sec	16 sec	8 sec
Philip St	0.59	.24	.17	.02
Far St	0.12	.01	.03	.02

'Before' and 'after' lane drift change scores were calculated for the Phillip St and Far St sites (i.e., 'Before' – '24sec', 'Before' – '16sec', and 'Before' – '8sec'). Lane drift change scores for the Phillip St and Far St sites were then compared at each dwell time using a paired samples *t*-test.

Paired samples *t*-tests revealed that (compared to baseline):

- There was a significant difference between the Phillip St and Far St site lane drift instances at the 24 second dwell time ($t(143) = 2.66$, $p = .009$).
- There was a significant difference between the Phillip St and Far St site lane drift instances at the 16 second dwell time ($t(143) = 3.93$, $p < .001$).
- There was a significant difference between the Phillip St and Far St site lane drift instances at the 8 second dwell time ($t(143) = 5.95$, $p < .001$).

Together, these results suggest that the illumination of the billboard had a statistically significant impact on lane drift instances at 24s, 16s and 8s. As can be seen from Figure 3.1, there was a significant *decrease* (for this measure a larger number represents a larger decrease in the number of lane drift instances) in lane drift instances upon activation of the digital billboard, for all of the dwell times.

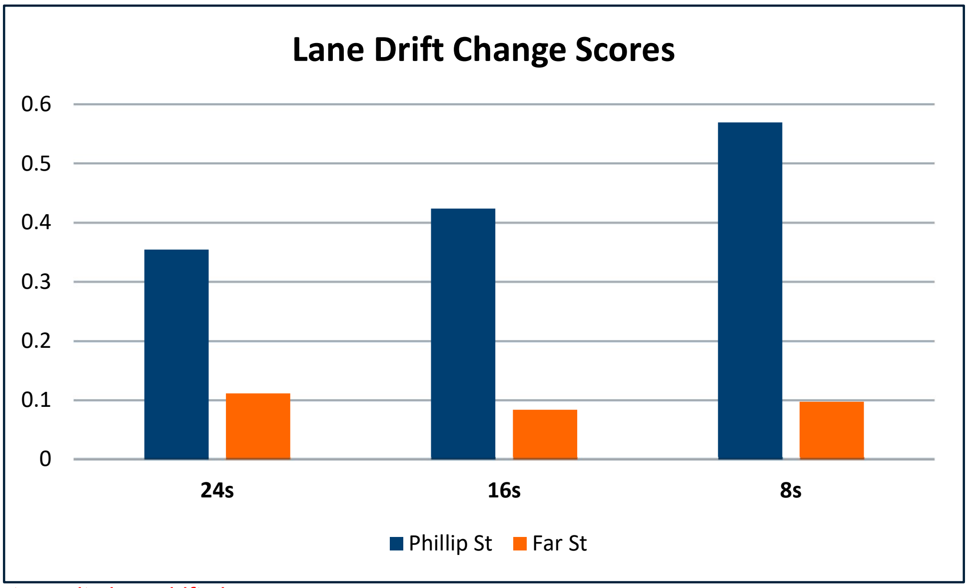

Figure 3.1: Gladstone site lane drift change scores

To assess whether there was any difference between the three dwell times in the magnitude of their impact, Far St lane drift change scores were then subtracted from Phillip St lane drift change scores, and paired samples *t*-tests were conducted on each dwell time (i.e., 24s x 16s, 24s x 8s, and 16s x 8s). Again, significance levels were evaluated at a Bonferroni-corrected alpha level of .017 (.05 x 3 dwell time comparisons).

Paired samples *t*-tests revealed that:

- There was a significant difference between lane drift instances at the 24s dwell time and 8s dwell time ($t(143) = -1.391$, $p < .001$).
- There was a significant difference between lane drift instances at the 16s dwell time and 8s dwell time ($t(143) = -4.196$, $p = .006$).
- There was no significant difference between lane drift instances at the 24s dwell time and 16s dwell time ($t(143) = -2.77$, $p = .166$).

Figure 3.2 shows these differences visually.

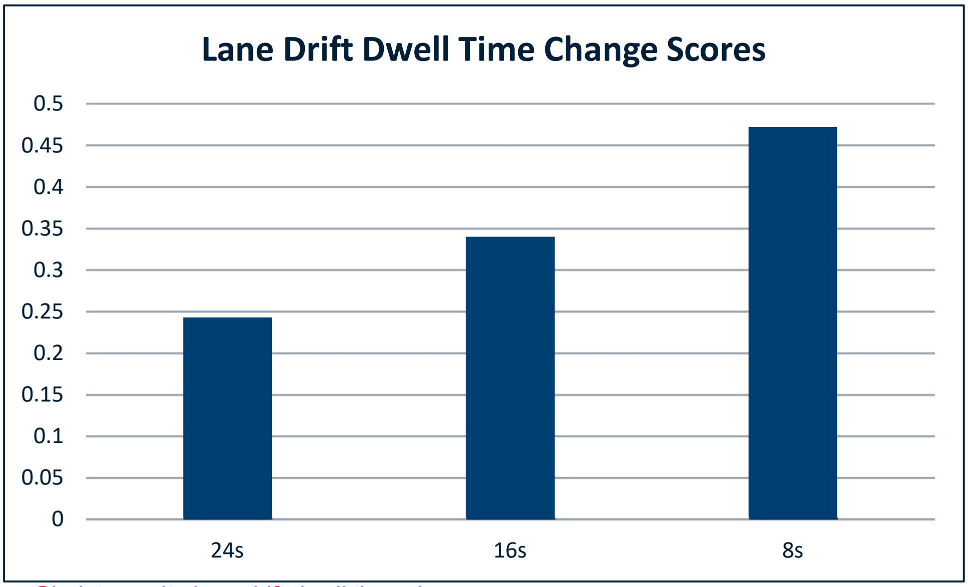

Figure 3.2: Gladstone site lane drift dwell time change scores

3.1.2 Stopping over the line

Table 3.2: Stopping over the line (mean number of instances)

Site	Period			
	Before	24 sec	16 sec	8 sec
Philip St	2.30	1.30	6.90	3.24
Far St	1.32	3.17	3.32	3.86

'Before' and 'after' 'stopping over the line' change scores were calculated for the Phillip St and Far St sites (i.e., 'Before' – '24sec', 'Before' – '16sec', and 'Before' – '8sec'). 'Stopping over the line' change scores for the Phillip St and Far St sites were then compared at each dwell time using a paired samples *t*-test.

Paired samples *t*-tests revealed that (compared to baseline):

- There was a significant difference between the Phillip St and Far St site 'stopping over the line' instances at the 24 second dwell time ($t(143) = 8.67$, $p < .001$).
- There was a significant difference between the Phillip St and Far St site 'stopping over the line' instances at the 16 second dwell time ($t(143) = -7.42$, $p < .001$).
- There was a significant difference between the Phillip St and Far St site 'stopping over the line' instances at the 8 second dwell time ($t(143) = 4.29$, $p < .001$).

Together, these results suggest that the illumination of the billboard had a statistically significant impact on 'stopping over the line' instances at 24s, 16s and 8s. Figure 3.2 shows these results visually. However, the effect is qualitatively different for 24 and 8 seconds compared to 16 seconds. At both the 24 and 8 sec dwell times the activation of the billboard *reduced* the incidence of stopping over the line, while at the 16 second dwell time there was an increase relative to the control site.

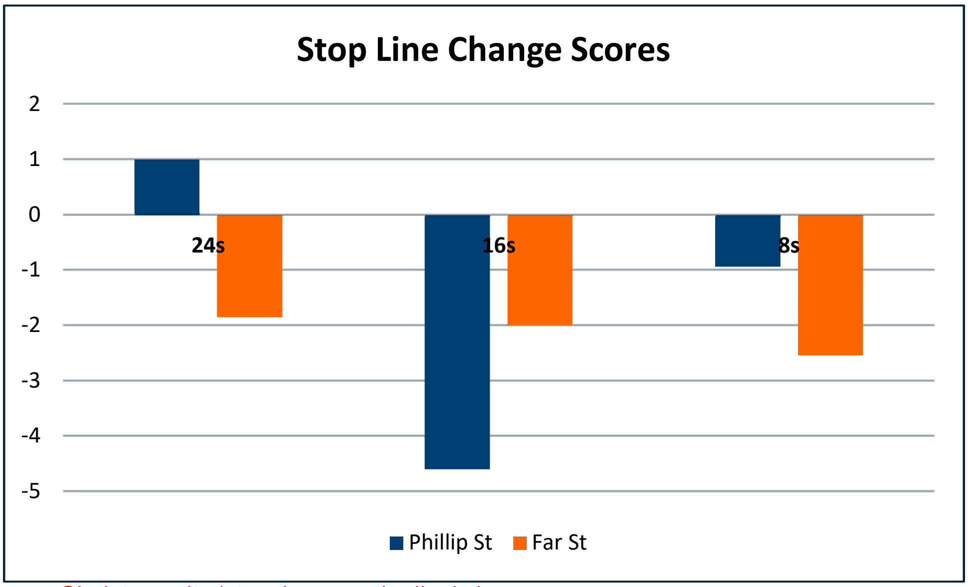

Figure 3.3: Gladstone site 'stopping over the line' change scores

Far St lane 'stopping over the line' scores were then subtracted from Phillip St lane 'stopping over the line' scores, and paired samples *t*-tests were conducted on each dwell time (i.e., 24s x

16s, 24s x 8s, and 16s x 8s). Again, significance levels were evaluated at a Bonferroni-corrected alpha level of .017 (.05 x 3 dwell time comparisons).

Paired samples *t*-tests revealed that:

- There was a significant difference between 'stopping over the line' instances at the 24s dwell time and 16s dwell time ($t(143) = 13.804$, $p < .001$).
- There was a significant difference between 'stopping over the line' instances at the 16s dwell time and 8s dwell time ($t(143) = -7.996$, $p < .001$).
- There was a significant difference between 'stopping over the line' instances at the 24s dwell time and 8s dwell time ($t(143) = 2.928$, $p = .004$).

Figure 3.4 shows these differences visually.

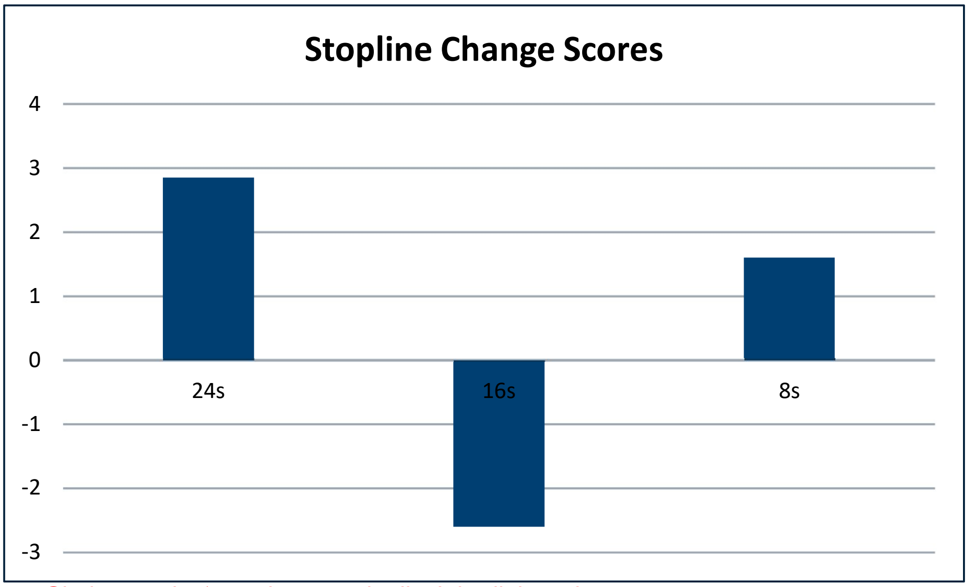

Figure 3.4: Gladstone site 'stopping over the line' dwell time change scores

3.2 Surfer's Paradise Site

In order to assess whether there was any evidence of a negative impact from the digital billboard being lit, 'before' and 'after' change scores were subjected to a paired samples *t*-test for each dwell time. The main comparison of interest was any difference between the two sites (Elkhorn Ave and Cavill Ave) in lane drift and instances of 'stopping over the line', following activation of the digital billboard. Significance levels were evaluated at a Bonferroni-corrected alpha level of .017 (.05 x 3 dwell time comparisons).

There were no incidents in any of the time periods examined.

3.2.1 Lane drift

Table 3.3: Lane drift (mean number of instances)

Site	Period			
	Before	30 sec	20 sec	10 sec
Northern Leg				
▪ Elkhorn Ave	1.38	0.69	0.98	1.51
▪ Cavill Ave	0.05	0.01	0.03	0.01
Western Leg				
▪ Elkhorn Ave	3.82	3.15	4.16	4.41
▪ Cavill Ave	0.36	0.58	0.17	0.37

'Before' and 'after' lane drift change scores were calculated for the Elkhorn Ave and Cavill Ave sites (i.e., 'Before' – '30sec', 'Before' – '20sec', and 'Before' – '10sec'). Lane drift change scores for the Elkhorn Ave and Cavill Ave sites were then compared at each dwell time using a paired samples *t*-test. It was determined that the Northern leg and Western leg data were equivalent in terms of distribution, and both legs were therefore collapsed to create a single measure for each road.

Paired samples *t*-tests revealed that (compared to baseline):

- There was a significant difference between the Elkhorn Ave and Cavill Ave site lane drift instances at the 30 second dwell time ($t(143) = 4.19$, $p < .001$).
- There was no significant difference between the Elkhorn Ave and Cavill Ave site lane drift instances at the 20 second dwell time ($t(142) = -.47$, $p = .639$).
- There was no significant difference between the Elkhorn Ave and Cavill Ave site lane drift instances at the 10 second dwell time ($t(142) = -1.77$, $p = .078$).

As can be seen from Figure 3.3 there was a *reduction* in mean lane drift instances at the 30 second dwell time.

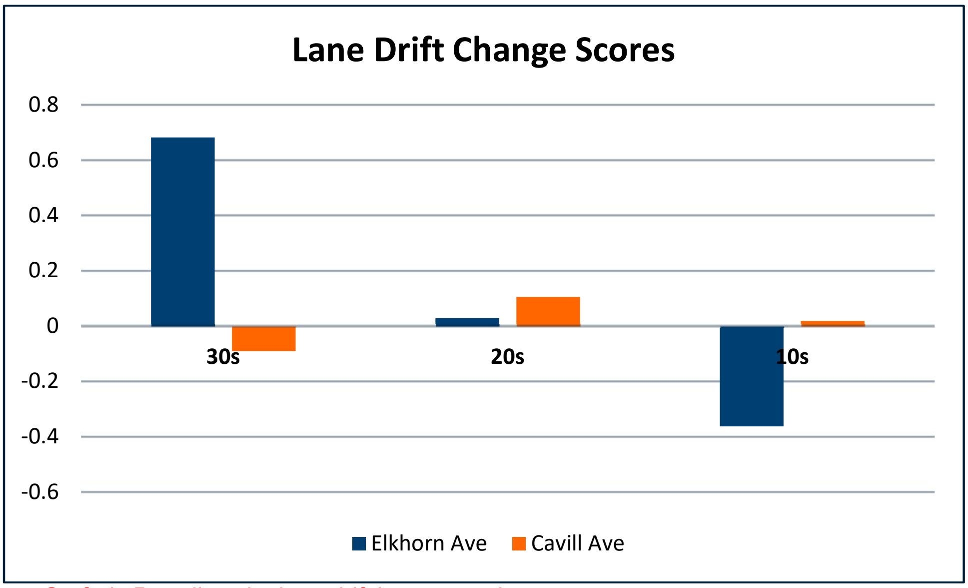

Figure 3.5: Surfer's Paradise site lane drift instances change scores

In order to assess whether there was any difference between the three dwell times, Cavill Ave lane drift change scores were then subtracted from Elkhorn Ave lane drift change scores, and paired samples *t*-tests were conducted on each dwell time (i.e., 30s x 20s, 30s x 10s, and 20s x 10s). Again, significance levels were evaluated at a Bonferroni-corrected alpha level of .017 (.05 x 3 dwell time comparisons).

Paired samples *t*-tests revealed that:

- There was a significant difference between lane drift instances at the 30s dwell time and 20s dwell time ($t(143) = 4.822$, $p < .001$).
- There was a significant difference between lane drift instances at the 30s dwell time and 10s dwell time ($t(143) = 6.241$, $p < .001$).
- There was no significant difference between lane drift instances at the 20s dwell time and 10s dwell time ($t(143) = 1.793$, $p = .075$).

Figure 3.6 shows these differences visually.

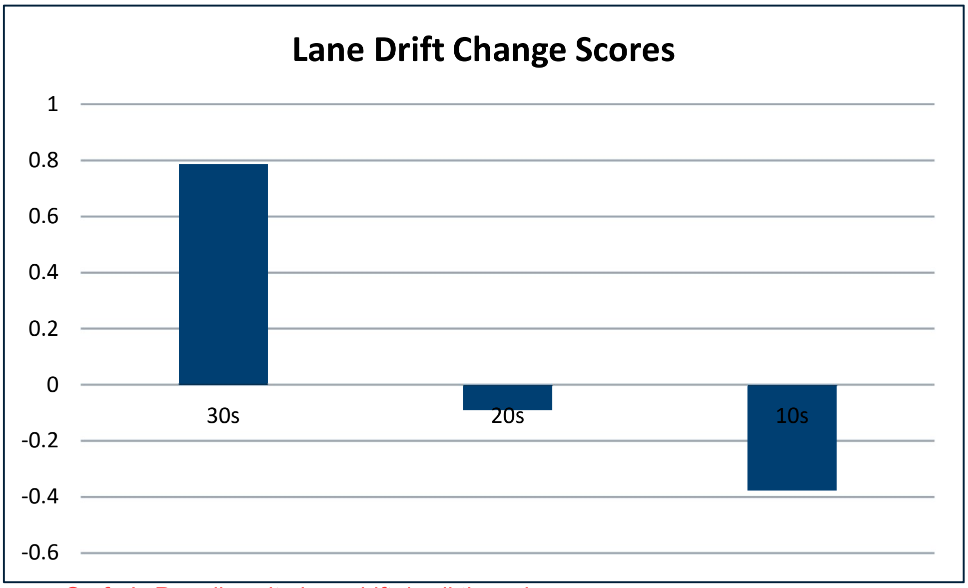

Figure 3.6: Surfer's Paradise site lane drift dwell time change scores

3.2.2 Stopping over the line

Table 3.4: Stopping over the line (mean number of instances)

Site	Period			
	Before	30 sec	20 sec	10 sec
Northern Leg				
▪ Elkhorn Ave	6.88	2.15	3.15	2.77
▪ Cavill Ave	2.07	2.01	2.01	1.67
Western Leg				
▪ Elkhorn Ave	2.91	1.97	1.15	1.29
▪ Cavill Ave	3.07	2.28	4.43	4.20

'Before' and 'after' 'stopping over the line' change scores were calculated for the Elkhorn Ave and Cavill Ave sites (i.e., 'Before' – '30sec', 'Before' – '20sec', and 'Before' – '10sec'). 'Stopping over the line' change scores for the Elkhorn Ave and Cavill Ave sites were then compared at each dwell time using a paired samples *t*-test. It was determined that the Northern leg and Western leg data were equivalent in terms of distribution, therefore both legs were collapsed to create one measure for each road.

Paired samples *t*-tests revealed that (compared to baseline):

- There was a significant difference between the Elkhorn Ave and Cavill Ave site 'stopping over the line' instances at the 30 second dwell time ($t(143) = 8.75$, $p < .001$).
- There was a significant difference between the Elkhorn Ave and Cavill Ave site 'stopping over the line' instances at the 20 second dwell time ($t(143) = 15.72$, $p < .001$).
- There was a significant difference between the Elkhorn Ave and Cavill Ave site 'stopping over the line' instances at the 10 second dwell time ($t(143) = 15.65$, $p < .001$).

These results show that the illumination of the billboard had a statistically significant impact on 'stopping over the line' instances at 30s, 20s and 10s. As can be seen from Figure 3.4 the impact from illumination of the billboard was a *reduction* in the number stopping over the line instances.

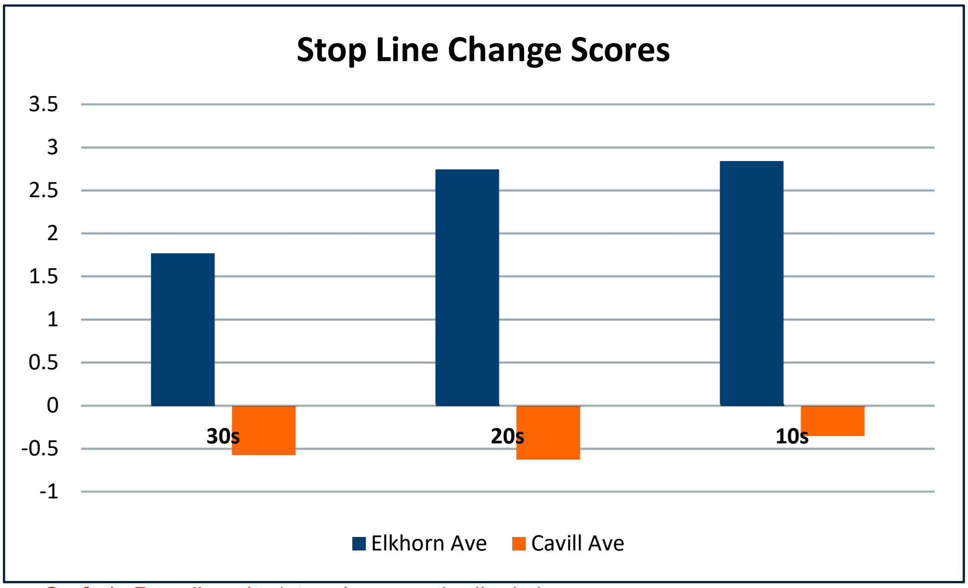

Figure 3.7: Surfer's Paradise site 'stopping over the line' change scores

In order to assess the differences between each dwell time Cavill Ave 'stopping over the line' change scores were then subtracted from Elkhorn Ave 'stopping over the line' change scores, and paired samples *t*-tests were conducted on each dwell time (i.e., 30s x 20s, 30s x 10s, and 20s x 10s). Again, significance levels were evaluated at a Bonferroni-corrected alpha level of .017 (.05 x 3 dwell time comparisons).

Paired samples *t*-tests revealed that:

- There was a significant difference between 'stopping over the line' instances at the 30s dwell time and 20s dwell time ($t(143) = -3.954$, $p < .001$).
- There was a significant difference between 'stopping over the line' instances at the 30s dwell time and 10s dwell time ($t(143) = -3.297$, $p = .001$).
- There was no significant difference between 'stopping over the line' instances at the 20s dwell time and 10s dwell time ($t(143) = .883$, $p = .379$).

Figure 3.8 shows these differences visually.

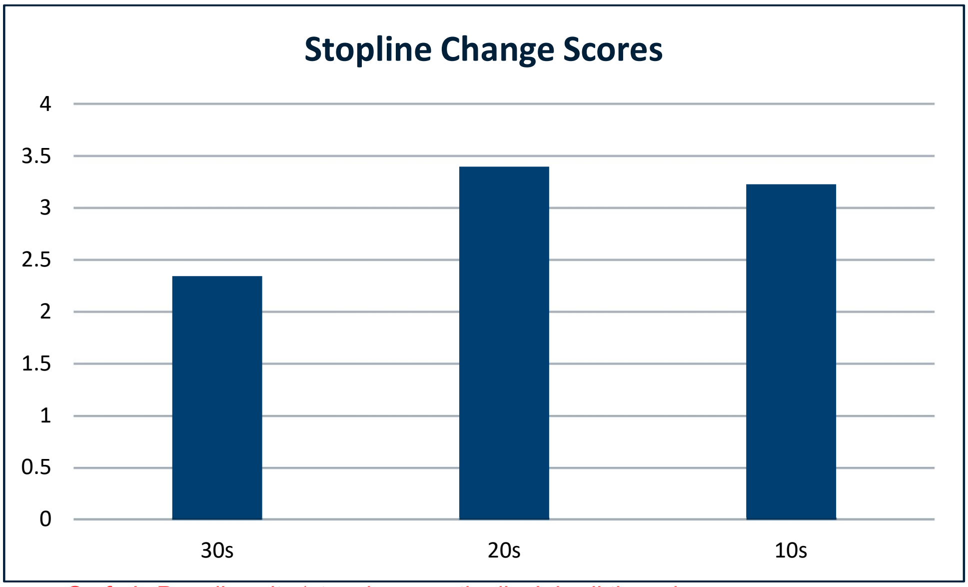

Figure 3.8: Surfer's Paradise site 'stopping over the line' dwell time change scores

4 DISCUSSION

The purpose of the current evaluation was to assess the impact of the operation of the digital billboards at the intersection of Phillip St and Dawson Highway in Gladstone, and the intersection of Elkhorn Ave and Surfer's Paradise Blvd in Surfer's Paradise on driver performance.

Contrary to an hypothesis that digital billboards at demanding locations will inevitably create enough distraction to negatively affect vehicle control performance, the current evaluation found that, at all dwell times, vehicle lateral control performance either improved or was unaffected by the digital billboards presence.

Similar results were obtained for stopping over the line instances. In all but one of the six dwell time-site combinations (the exception being 16sec-Gladstone[2]), the presence of the digital billboard had a positive effect on stopping over the line violations.

These results beg the question of why previous research has often demonstrated a negative impact on vehicle control from visual distraction (e.g. Kountouriotis & Merat, 2016; Liang & Lee, 2010). A possible explanation is that the source of visual distraction in these studies usually comes from an in-vehicle device that requires drivers to take their eyes off the forward roadway in order to interact with the device. For example, Liang and Lee (2010) utilised a LCD touch screen located 25° laterally and 20° vertically below drivers' line of sight. In their driving simulator study showing a negative impact on lateral control from a digital billboard, Schieber et al. (2014) placed the billboard off to the side of the road under conditions that encouraged drivers to take their eyes off the forward roadway. By contrast, in the current evaluation, the billboards were more or less straight ahead for the assessed drivers. As a result, the billboards did not require drivers to move their eyes from the forward roadway in order to apprehend the content of the billboards.

The current results are however consistent with previous research showing that drivers are able to safely view roadway signage for relatively long periods of time if the sign is positioned at a relatively narrow angular offset from the centreline of the road (e.g. Schieber, Burns, Myers, Gilland, & Willan, 2004). If it is indeed the case that the key element in creating a negative impact on vehicle control from visual distraction is a physical location of the source of distraction that encourages drivers to move their eyes off the forward roadway then digital billboards that are 'front and centre' rather than off to the side should be relatively benign in their impact, irrespective of whether they are, for example, located at an undemanding midblock location or a demanding intersection. This hypothesis could be tested effectively in a driving simulator and the results would have significant practical and guidance implications.

Interestingly, the current evaluation didn't simply show a benign impact from digital billboards that were 'front and centre', it actually showed a positive impact on vehicle control from the presence of these digital billboards. This result is consistent with some findings in the driver distraction literature. For example, Engström, Johansson, & Östlund (2005) and He & McCarley (2011) both found that additional cognitive load can decrease lane keeping variability. In the

[2] The explanation for this anomaly is unclear at this stage. However, post hoc analysis of the logs of the material presented during the study shows that not all the material was presented at all dwell times. In particular, it was the case that the 16 sec dwell time missed out on a subset of the adverts and received a higher proportion of the remaining adverts than the other dwell times. It is hoped that this 'content' hypothesis will be the subject of further testing in subsequent studies.

current study the presence of the digital billboards would have created some additional cognitive load. There is still some debate about exactly how this 'positive' impact of cognitive load should be interpreted (Penghui, Merat, Zheng, Markkula, Li & Wang, 2018). However, from a practical perspective, in the road environments investigated here, and given the complete lack of incidents, it would be difficult to reconcile the observed reduction in lane excursions with an increased crash risk.

Furthermore, the 'positive' impact of digital billboards in the current evaluation did not occur exclusively with respect to lateral control. This effect was also observed (with one exception) for stopping over the line violations. This is important because it rules out the possibility of a very specific and hence less practically significant impact from digital billboards. Stopping over the line suggests a failure to appropriately register the red state of the signals. This could result from 'back dropping' where colour contents in the billboard display are confusable with signal colours (see Austroads, 2013). The decrease in stopping over the line violations in the presence of the billboard suggests that such confusion did not occur in this evaluation. Stopping over the line violations could also result from change blindness for signal changes. While there is considerable evidence that distraction can increase change blindness in driving situations (e.g. McCarley et al.,2004) this research has mostly considered distraction from mobile phone conversations rather than external visual distraction. The decrease in stopping over the line violations in the presence of the billboard suggests that change blindness did not occur in this evaluation. Interestingly a recent study by Pammer et al. (2014), although not concerned with a driving task per se, did find that under certain conditions in the laboratory that a visual distraction could reduce the incidence of change blindness.

In conclusion, the current evaluation investigated the impact of the presence of digital billboards on vehicle control performance. The sites evaluated were relatively complex signalised intersections. Because of the cognitive demands associated with negotiating a signalised intersection, these are the kinds of sites where it might be expected that drivers would display impairment from distraction. However, there was almost no evidence that the digital billboards at these locations impaired driving performance. Clearly, in real world situations the impact from the visual distraction from digital billboards is complex, and some in some situations, such as the installations evaluated here, there can be an apparent positive impact on driving performance from the presence of a digital billboard. If the parameters of how and when this positive impact occurs can be precisely specified this would prove enormously valuable for all stakeholders.

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