Automated Vehicles and the Readiness of Western Australian roads

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Abstract

An assessment of various line markings at nine sites along the Great Southern Highway, approximately 155 km South-East of Perth in the Wheat-Belt region of Western Australia was performed using two vehicles equipped with lane departure warning (LDW) systems during three days of on-road trials. Crossing events were performed with each trial vehicle by initially travelling at the speed limit in the centre of the lane and then instigating a drift to the left or right. A video system with two cameras, one viewing the wheel approaching the line marking of interest and one viewing the vehicle's dashboard, was used to record whether a warning was triggered for each crossing event. Overall, 189 crossing events were measured in the data sample. Of these, 154 (81%) gave an accurate warning, with a total of 35 (19%) warning failures. Marked centrelines had the highest warning accuracy (95%), followed by marked edge lines (90%). Unmarked road edges had the lowest accuracy rate (39%). Warning failures were attributed to the absence of a marked line; the vehicle travel speed being less than the manufacturer recommended speed for system operation; the line marking being difficult to see; and the line marking retro-reflectivity and/or the daylight brightness being low. The findings of this study show that LDW systems are capable of providing appropriate warnings in rural road environments where there are suitable line markings. It was clear that the line markings being utilised on WA roads, where they have been well maintained to provide sufficient levels of contrast with the road surface and retro-reflectivity, comfortably meet this level of suitability. Quantifying the exact levels of line marking contrast or retro-reflectivity required for the effective operation of lane departure warning systems was beyond the scope of this project.

Keywords

Lane Departure Warning, Lane Keep Assist, Autonomous Vehicles

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ABBREVIATIONS

The following abbreviations are used throughout the report:

ACC – Adaptive Cruise Control

AEB – Autonomous emergency braking

CASR – Centre for Automotive Safety Research

C-MARC – Curtin-Monash Accident Research Centre

LDW – Lane Departure Warning

LKA – Lane Keep Assist

LSS – Lane Support System

MRWA – Main Roads Western Australia

SLK – Straight Line Kilometre

WA – Western Australia

EXECUTIVE SUMMARY

Introduction

With the advent of automated vehicle technologies, the readiness of road infrastructure in Western Australia (WA) must be assessed, and areas requiring modification or development must be identified. The development of automated vehicle-ready road treatments is particularly pertinent in rural and remote WA where nearly 50% of fatalities occur of which the majority can be attributed to run off road crashes. It has been suggested that the number of run off road crashes in regional areas could be significantly decreased if vehicles were more capable of warning drivers of unintentional lane departure through the use of LDW systems or if vehicles were able to physically prevent unintentional lane departure with lane keeping assist (LKA). In regional and rural WA, road markings may be less than optimal to support this technology which may limit their reliability and effectiveness.

This report describes the results of an on-road trial of the positional sensitivity of a typical LDW system when interacting with roads in regional WA.

Method

Two vehicles (anonymised in this report), equipped with commercial lane departure warning systems were used to collect data during three days of on-road trials that assessed various line markings and road edges on rural roads in WA. Data was collected at five planned sites along the Great Southern Highway, between the towns of Brookton and Cuballing, approximately 155 km South-East of Perth in the Wheat-Belt region of WA. The five sites were selected to provide a variety of line marking types for assessment. Additionally, data was also collected at a further four ad-hoc sites, in the same general area as the planned sites, where interesting line markings or LDW system behaviour were observed.

An evaluation of these trial sites was performed, which involved collecting details on factors such as the line markings at the site, the width of the lanes, and the retro-reflectivity (a measure of line 'brightness' under specific lighting conditions) of the line markings.

At each site a number of line (or road edge) crossing events were performed with each trial vehicle by initially travelling at the speed limit in the centre of the lane and then instigating a drift to the left or right. A video system with two cameras, one viewing the left/right wheel of interest and one viewing the vehicle's dashboard, was used to record whether a warning was triggered for each crossing event. Other pertinent details regarding each crossing event were also recorded, such as the daylight brightness (lux), temperature, and the presence of sun glare.

Results

Overall, 189 crossing events were measured in the data sample. Of these, 154 (81%) gave an accurate warning, with a total of 35 (19%) warning failures.

At the planned sites, all of which were located on the Great Southern Highway, there were four warning errors from a total of 110 crossing events. At the ad-hoc sites, which were chosen because some warning errors were expected, 48 of 79 of crossing events gave an accurate warning.

Overall, marked centrelines had the highest warning accuracy in the data set (95%). Marked edge lines also had a high accuracy rate (90%). Unmarked road edges had the lowest accuracy rate (39%). There were 35 warning failures in the data set. These failures can be attributed in the following way:

- 12 occurred where there was absence of a marked line;
- 4 occurred when the travel speed was below than the manufacturer recommended speed for system operation;
- 13 occurred in the absence of a marked line along with the travel speed being below than the manufacturer recommended speed;
- 5 occurred when retro-reflectivity and daylight brightness levels were both low, or the field-work team noted they had trouble seeing the line; and
- 1 warning failure was unexplained.

Discussion

The findings of this study show that LDW systems are capable of providing appropriate warnings in rural road environments where there are suitable line markings. It was clear that the line markings being utilised on WA roads, where they have been well maintained to provide sufficient levels of contrast with the road surface and retro-reflectivity, comfortably meet this level of suitability. This was true regardless of the specific type of line marking (e.g. solid, dashed, double barrier, etc.).

Despite this general finding that LDW systems function well with line markings on WA rural roads, there were several situations where warnings failed to trigger. In most cases the situations leading to these failures were noted as limitations in the LDW system user manuals.

While it was not possible to determine a quantitative definition of a suitable line marking, there were some indications of what may be important. The level of retro-reflectivity, combined with the level of available daylight brightness, did appear to indicate where LDW systems may have difficulty in detecting a line marking. There was also an indication that line marking visual contrast is important to consider.

Recommendations

In light of the findings of this study, a number of recommendations are appropriate. First, the proportion of rural roads in WA with line markings (edge and centreline) should be increased. Second, all line markings should continue to be maintained to a suitable level. Other types of road maintenance which results in the creation of 'pseudo lines' should be avoided and rectified in locations where it has already occurred, so they do not confuse LDW systems. Pseudo lines are created when markings, gouges, scratches, or patching are applied in a thin longitudinal line along the roadway. Finally, in noting that lane departure warnings are triggered as a vehicle crosses a line marking, sufficient space for drivers to recover (e.g. sealed roadside shoulders) should be provided.

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1 INTRODUCTION

This report comprises Phase 2 of the Autonomous Vehicles study. Phase 1 consisted of an in-depth literature review of automated vehicle technology.

There have been at least 286,000 crashes on Australian roads since 2010 with the total number of fatalities each year fluctuating from roughly 1,150 to 1,350 people. (Road Safety Commission (RSC), 2016). In Western Australia (WA) alone, it is estimated that these fatalities cost the community between $3 million and $8 million every year (RSC, 2016). Despite various road safety initiatives, WA's "*Toward Zero*" strategy acknowledges the need to invest in additional factors, one of these being vehicle safety (RSC, 2018b).

Eventually, automated vehicle technology will limit or remove the need for a human driver altogether. Over the past decade there have been significant advances in vehicle safety with the development and inclusion of increasingly advanced driver-assistance systems in new vehicles. These include lane departure warning (LDW) systems, lane keeping assist (LKA) systems, adaptive cruise control (ACC) and autonomous emergency braking (AEB) systems. Further advances in vehicle safety include the development of vehicular technologies that support semi and fully automated driving. It is predicted that these technologies will reduce the incidence of crashes and the burden of injuries by removing many aspects of driver behaviour and error (National Transport Commission, 2017).

Semi-automated and automated vehicle technologies have been classified within a hierarchical 'level' system by The Society of Automotive Engineers (SAE International, 2016). Currently, automated vehicle technology has typically been scored level 1 to 2, of a 5-level scale. The European Road Transport Research Advisory Council (ERTRAC) has indicated that level 1 and 2 technologies will become more common on the road within the next five years (European Road Transport Research Advisory Council, 2015).

Level 0 technology refers to the on-board automated warning systems in a vehicle that aid a driver by alerting them to danger via warning lights and sounds. However, the vehicle has no capacity to take control from the driver. LDW is a Level 0 technology that seeks to prevent crashes which are caused by a driver allowing their vehicle to unintentionally drift out of its lane while travelling at speed. If there is an indication that the vehicle is unintentionally wandering out of its lane, the LDW system alerts the driver, usually through flashing lights or vibration of the steering wheel.

Level 1 technology refers to a vehicle that can use information about the surrounding driving environment to perform one aspect of the driving task automatically (either steering or braking/accelerating). This could include a vehicle automatically turning the steering wheel while a human driver controls the brake and accelerator when performing parking manoeuvres. In the case of Level 1, although the vehicle can automatically perform limited aspects of the dynamic driving task, a human driver is still required to be inside the vehicle at all times. Level 1 technology, such as lane keeping assist, is currently available in some vehicles on Australian roads. Level 2 technologies are similar to Level 1, but instead of the vehicle only being able to take control of one aspect of the dynamic driving task, it can control both the steering and accelerating/braking functions for limited amounts of time, provided that a human driver remains present.

With the advent of this technology, the readiness of road infrastructure in Western Australia must be assessed, and areas requiring modification or development in preparation for these emerging technologies must be identified. It is possible that the existing road network may need to change to accommodate the expected increase in the automated vehicle technologies. As an indication, recent reports by Main Roads Western Australia (Somers and Weeratunga, 2015) and the Curtin Monash Accident Research Centre (C-MARC) (Palamara et al., 2016) have demonstrated a need to accommodate the emerging automated technologies such as Lane Departure Warning Systems on the WA road network.

Although the road network itself has limited influence over the majority of Level 0, Level 1 and Level 2 technologies, key features like lane departure warning, lane keeping assist and advanced parking assist may be affected by the quality and breadth of certain road infrastructure. It is possible to influence the functionality of these systems via line marking type, configuration of the road, the types of road surface used, and the posted speed limits (Sage, 2016). For example, lane departure warning systems may be impaired in some circumstances by glare associated with the reflection of the sun off the road, or if the road has a certain contrast (Subaru 2013).

They may also have issues with deciphering old or faded line marking, depending upon location and time of day (Richards, 2014).

Australia's vast size and the huge diversity and range of the road network present issues in addressing the road network limitations for automated vehicles. This might make it near-impossible to introduce and maintain immense amounts of additional infrastructure that may be required in the next five years. It is therefore essential that any modifications to the existing road network are targeted at critical areas and must be reasonably achievable from an expenditure perspective.

The development of automated vehicle-ready road treatments is particularly pertinent in rural and remote WA where nearly 50% of fatalities occur (RSC, 2018c; RSC, 2018a). Typically, rural roads attract a high volume of crashes, several of which can be attributed to drivers failing to realise that their vehicle is unintentionally drifting out of the correct lane (Roman, 2016). According to Scanlon et al., (2015), the number of crashes on regional roads could be significantly decreased if vehicles were more capable of warning drivers of unintentional lane departure through the use of LDW or if vehicles were able to physically prevent unintentional lane departure through LKA. In regional and rural WA, road markings and signage may be less than optimal to support this technology which has the potential to reduce run off road crashes.

This project will implement one of the key recommendations from the Phase 1 report to undertake an on-road trial of the positional sensitivity of a typical LDW system when interacting with MRWA roads in regional WA.

1.1 Aims and objectives

The overall aim of the projects was to assess the readiness of WA rural roads for autonomous driving and driver assistance technologies. Specific objectives included:

- Undertake an on-road trial of the positional sensitivity of LDW systems on five regional WA road sections as per the methodology proposed by Palamara et al. (2016)
- Analyse the variation in positional sensitivity in relation to a combination of on-road test variables (e.g. vehicle speed, lane marking type, or line marking retro-reflectivity).

- Make recommendations regarding the performance, suitability and/or the need for upgrades of road infrastructure to support LDW in regional WA.

2 METHODS

2.1 Trial vehicles

Two commercially available passenger vehicles were utilised for the purposes of assessing the line markings at the trial sites described below. Both vehicles were 2018 model versions and were provided (in-kind) by separate manufacturers on the condition that they remain anonymous during the reporting of the study results. As such, the two vehicles are referred to in this report as ‘Vehicle A’ and ‘Vehicle B’, and sections of some images have been blurred to prevent the identification of vehicle make or model.

Both vehicles were equipped with a modern lane support system that included a lane departure warning feature. The system on each vehicle operated slightly differently and had a number of known limitations as described below.

2.1.1 Vehicle A

Vehicle A was a 5-door hatchback with a lane support system that used a single camera (it is not known whether the camera operates in full colour or grey-scale). The user manual stated that the system may not operate at speeds below 60 km/h. There was no statement regarding whether the system was capable of detecting the edge of the road. However, it did note that it would have difficulty in the following conditions:

- Line markings that are worn or faded,
- Line markings that are a similar colour to the road surface,
- Line markings that are very thick,
- Like markings that are very narrow,
- Where there are other markings on the road that are similar to line markings,
- Where there are more than two distinct line markings,
- Where there are shadows over line markings, and
- Where there is not sufficient lighting

2.1.2 Vehicle B

Vehicle B was a sedan with a lane support system that used stereo cameras operating in full colour. The system is designed to work with line markings but not with the edge of the road. The user manual stated that the system may not operate at speeds below 50 km/h and may have difficulty with the following conditions:

- Line markings that are worn or faded,
- Line markings that are yellow in colour,
- Line markings that are a similar colour to the road surface,
- Line markings that are very narrow,
- Where there are more than two distinct line markings,
- Where there are tire marks,
- Where there are markings from road repair
- Where there are shadows from guard-rails, and
- Where there is residue from line markings that have been removed.

2.2 Test equipment

2.2.1 Video Vbox HD2

A Racelogic Video Vbox HD2 data logger was utilised as the main data collection system. The HD2 system is equipped with two 1080p video cameras with real-time synchronisation to data collected by a GPS engine operating at 10 Hz. The video streams from both cameras are recorded and can be further enhanced with graphical overlays showing information collected by the GPS engine.

For this study, the two cameras were positioned to capture images of the vehicle instrument panel, where the lane departure warnings would appear, and either the left or right front wheel, such that a line crossing event could be observed. An image of this camera layout can be seen in Figure 2.1. Also note the graphical overlay, in bright green, which shows details of the current vehicle speed, date, time, and filename, along with calibrated lines which display the lateral distance from the edge of the wheel.

The lines placed onto the graphical overlay were calibrated using a 10 cm scale that was placed perpendicular to the left or right tyre while the steering wheel was positioned in a neutral (straight ahead) position. The zero point of the scale was positioned such that it indicated the outermost edge of the tyre wall; usually the bulge of the tyre, rather than where the tyre makes contact with the road. Once the scale was positioned (see Figure 2.2), the lines were traced onto the graphical overlay along with text indicating the lateral distance between each line and the edge of the tyre.

The vehicle speed, date (in GMT), and time (in GMT) were sourced from the GPS signal collected by the HD2. Along with the video data, the system also recorded a number of other variables, such as acceleration and heading angle. All data collected by the HD2 was recorded onto an SD card for later retrieval.

Figure 2.1 Camera layout used to record line crossing events

Figure 2.2 Camera overlay being aligned using scale

2.2.2 LTL-X Retroreflectometer

A Delta LTL-X retroreflectometer (shown in Figure 2.3) was used to measure the retro-reflectivity of the line markings at the trial sites. The retroreflectometer operates by projecting a light source towards the line marking at an angle of 1.24° and then measuring the amount of light reflected at an angle of 2.29°. This provided a measure of the brightness of the line marking in car headlight illumination as seen by a driver at an observation distance of 30 meters. The retro-reflectivity is measured in units of milli-candelas per lux per square metre ($mcd/lx/m^2$).

While all data collection in this study occurred during daylight hours, without the need for headlight illumination, retro-reflectivity was used to provide an indication of the brightness of the line marking.

The retroreflectometer was operated by two experts in line marking audit and assessment from Main Roads Western Australia who accompanied the field-work team to the trial sites.

Figure 2.3 The LTL-X Retroreflectometer

2.2.3 QM-1584 digital light meter

A QM-1584 digital light meter was used to measure the current level of light (in lux) at the trial sites. This measure of daylight brightness provided an indication of the available light, which aids the cameras on the LDW systems to detect line markings.

2.2.4 Water truck

A water truck (shown in Figure 2.4) was utilised to provide a 'wet line' along the road at two of the rural trial sites. Water was sprayed through a hose onto the road as the water truck travelled along. The water truck was provided and operated by the local regional council in the relevant areas.

Figure 2.4 Water truck

2.3 Data collection procedure

The procedures that were followed for data collection during the on-road trials are described below. A separate procedure was defined for each of the two main activities involved in the trial; the evaluation of the trial sites and performing the line crossing events.

The data collection occurred during February 2018. The weather was typical of that time of year with temperatures ranging from 25°C to 35°C and generally clear sunny days.

2.3.1 Familiarisation activity

To assist with the field-work team's familiarity with the testing equipment and data collection procedures, a familiarisation activity was performed. This activity consisted of fitting a vehicle with the Video Vbox HD2 cameras, calibrating the cameras, travelling to a private test track, performing a mock site survey, and then performing a number of mock crossing events across a solid and dashed centreline. During each task the requirements of the relevant risk assessments and safe operating procedures were observed. The familiarisation activity allowed the field-work team to:

- Evaluate the appropriateness of the risk assessments and the practicality of the safe operating procedures, then make amendments where necessary;
- Determine the time required for equipment set-up, site evaluation, and to perform each crossing event assessment;
- Assess the data collection procedure, identify any gaps or limitations, and make improvements; and
- Practise the site evaluation and crossing event procedure to enable more efficient performance during the real study.

The learnings from the familiarisation activity contributed to the final data collection procedures outlined here.

2.3.2 Site evaluation

At the planned rural trial sites, the following procedures were undertaken. First, the site was inspected and assessed for safety. This included identifying safe places to turn around following a trial run in each travel direction as well as an appropriate location to set-up the test equipment. Then, with the assistance of traffic management, the site was surveyed to determine the layout of the line markings along with any other notable features. The retro-reflectivity of each relevant line marking was measured, and photographs of the site were taken.

2.3.3 Line crossing events

The line crossing event data was collected in 'runs'. A run consisted of the trial vehicle traversing the trial site in one direction. For each run, either the centreline or the outside line/edge of road was chosen as the line of interest.

Prior to a run the field-work team recorded the daylight brightness, temperature (as indicated by the vehicle dash), and any particular aspects of interest for the run, such as sun glare or water on the road. The Video Vbox HD2 system was then set to record and the run was started.

All runs were performed in the absence of other vehicles in the general vicinity, either in the same lane (leading or following) or in the opposite lane. If another vehicle entered the vicinity of the test area while a run was in progress (as outlined below), the run was aborted and repeated once the test area was clear.

At the beginning of the run, the driver would accelerate the trial vehicle to the speed limit at the trial site then start the process of obtaining crossing event data. This involved the driver making an attempt to cross over the line marking (or road edge) of interest; deemed to be a ‘crossing event’. Each crossing event was preceded by a short period spent travelling straight ahead near the centre of the travel lane. To initiate the crossing event the driver steered gently toward the line, rotating the steering wheel by no more than a few degrees. Typically, the driver would allow the wheel of the trial vehicle to cross over the line by somewhere between 50 mm and an entire tyre width. Once a crossing event was completed the driver steered the vehicle back to the centre of the travel lane and either commenced another crossing event or ended the run by pulling over (and halting the Video Vbox HD2).

During each crossing event, the response of the trial vehicle’s LDW system was noted. A positive response was recorded if the LDW system triggered a warning (buzzer and illuminated dash light) within a short distance of the vehicle’s tyre crossing the line. A negative response was recorded if no warning was triggered.

Where the crossing event involved a shoulder edge, it was sometimes deemed safest to not cross over onto the gravel shoulder. In these instances, a positive response was recorded if a warning was triggered on approach to the road edge and a negative response was recorded if it was obvious (by viewing the dashboard display) that the LDW system was not detecting the presence of the road edge.

2.4 Trial sites

A suitable length of rural road, representative of typical conditions in WA, was identified through consultation with Main Roads Western Australia. The identified route runs between the towns of Brookton and Cuballing, approximately 155 km South-East of Perth in the Wheatbelt region of WA, and consisted of a single lane undivided roadway. This route was selected due to the following favourable characteristics:

- Low traffic volumes, which minimised the potential for interaction between the field-work team and other road users;
- Sections of the route had received road resurfacing treatments within the past two years and was consequently in good condition;

- A significant number of straight sections (typically 100 m to 1,000 m in length) along the route provided favourable conditions for conducting the crossing events;
- There was a mixture of typical line marking stereotypes including barrier, double barrier, and broken; and,
- There was some variation in posted speed limits.

Five rural trial sites were selected along the Brookton to Cuballing route. These sites were selected such that the positional sensitivity of the LDW systems on the trial vehicles could be assessed with various line markings in several speed zones. The selected sites enabled the assessment of the following line markings:

- Broken centreline,
- Barrier-broken centreline,
- Broken-barrier centreline,
- Double barrier centreline,
- Audio-tactile edge line with sealed shoulder, and
- Audio-tactile edge line with sealed, dark shoulder encroaching onto carriageway.

Beyond the five selected trial sites, data was also collected at a further four extra sites in the same region. These extra sites were identified as locations with interesting line markings (which may test the capabilities of the LDW systems) by the field-work team while conducting the on-road trials.

In the sections below the five selected sites are referred to as the ‘planned sites’, and the extra four sites are referred to as the ‘ad-hoc sites’. While the site evaluation procedure described above was applied for all the planned sites, the ah-hoc sites were not typically surveyed, nor was their retro-reflectivity measured.

The locations of the planned trial sites are displayed in the map shown in Figure 2.5, labelled P1 to P5. Also shown in Figure 2.5 are the locations of the ad-hoc sites, labelled A1 to A4.

Each of the trial sites are described below with details regarding the location, line markings, and lane layouts. A summary of the line markings at each trial site, with a highlight of those markings that were assessed during the study, is provided in Table 2.1.

The sites along the Great Southern Highway are located with a straight line kilometre (SLK) reference. This SLK reference has its origin at the town of Northam and increases when travelling Southbound.

Figure 2.5 Location of trial sites

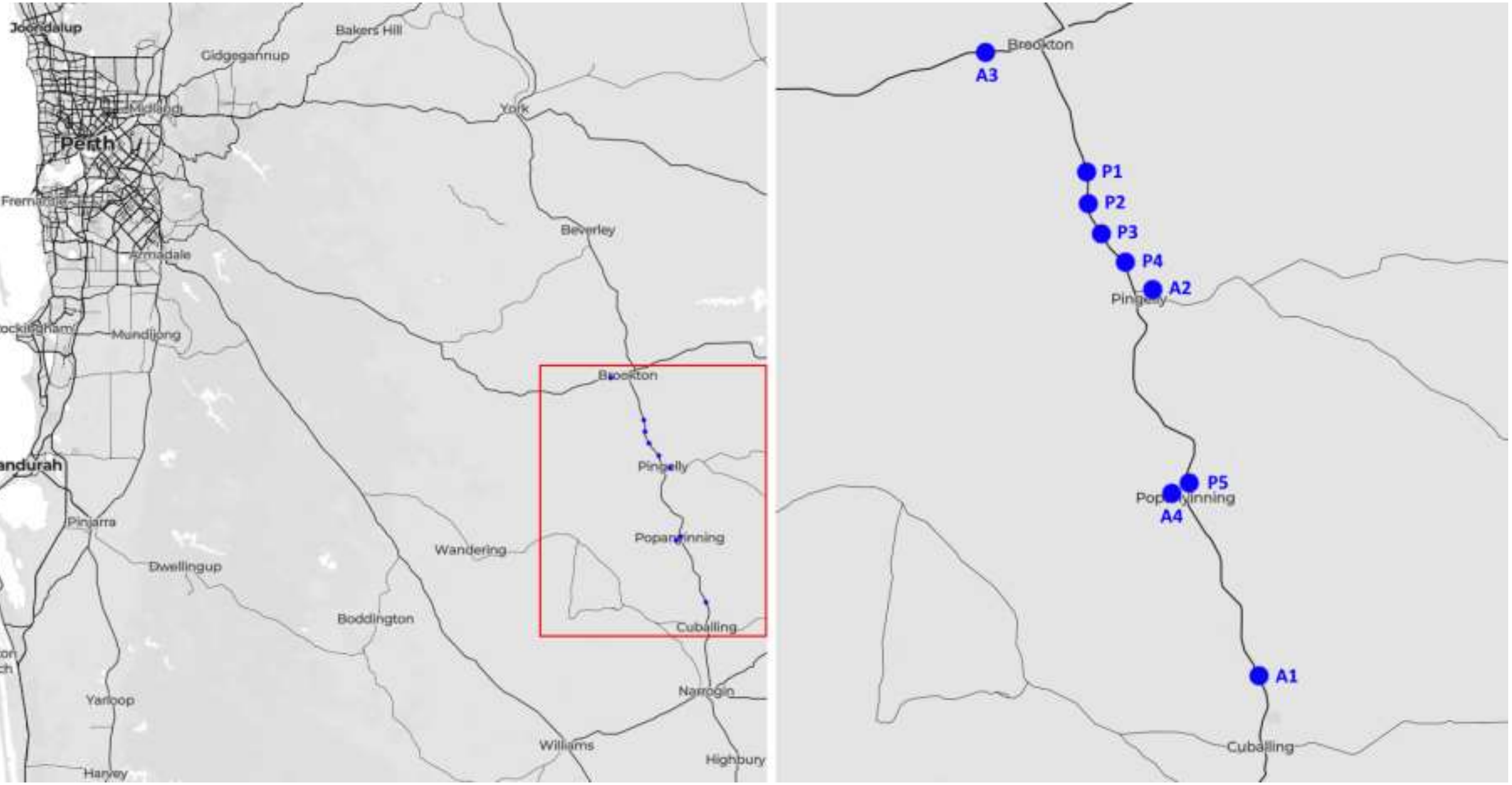


Table 2.1 Summary of trial sites line markings (assessed lines highlighted)

Site	Centreline type	Edge line type	Notes
P1	**Double barrier**	Audio-tactile	
P2	**Broken-Barrier**	Audio-tactile	
P3	**Broken**	**Audio-tactile**	
P4	**Broken**	Audio-tactile	Low centreline retro-reflectivity on one direction. Tested with water on road.
P5	Broken	**Audio-tactile with dark shoulder**	
A1	**Broken**	Audio-tactile	Difficult to see centreline in one direction.
A2	Broken	**None**	Some warnings triggered on edge of road. Tested with water on road.
A3	**Broken**	**Various**	Edge of road has pseudo lines, solid lines, no lines. Tested with sun glare.
A4	None	**None**	Narrow road with no lines marked.

2.4.1 Site P1: Great Southern Highway – SLK 108-109

Site P1 is located on the Great Southern Highway between SLK values of 108 and 109. The site has a double barrier centreline and audio-tactile edge lines. Only the centre line was subjected to testing. A photograph of the site is shown in Figure 2.6 and the dimensions of the road are shown in Table 2.2. Retro-reflectivity was measured at two locations at this site and the average of these measurements is shown in Table 2.3.

Figure 2.6 Site P1, Great Southern Highway (SLK 108-109)

Table 2.2 Typical road dimensions measured at Site P1

Element	Width (mm)
Southbound shoulder	1070
Southbound edge line	120
Southbound lane	3380
Barrier centreline (Southbound side)	100
Gap between double centre lines	80
Barrier centreline (Northbound side)	80
Northbound lane	3210
Northbound edge line	140
Northbound shoulder	1000

Table 2.3 Retro-reflectivity measured at Site P1

Direction	Centreline (mcd/lx/m²)	Edge line (mcd/lx/m²)
Northbound	201	No data
Southbound	105	No data

2.4.2 Site P2: Great Southern Highway – SLK 109-110

Site P2 is located on the Great Southern Highway between SLK values of 109 and 110. The site has a broken-barrier centreline line type and audio-tactile edge lines. The barrier-broken is found in a Northbound direction and the broken-barrier type line is found in a Southbound direction. Only the centre line was subjected to testing. A photograph of the site is shown in Figure 2.7 and the dimensions of the road are shown in Table 2.4. Retro-reflectivity was measured at two locations at this site and the average of these measurements is shown in Table 2.5.

Figure 2.7 Site P2, Great Southern Highway (SLK 109-110)

Table 2.4 Typical road dimensions measured at Site P2

Element	Width (mm)
Southbound shoulder	940
Southbound edge line	140
Southbound lane	3450
Broken centre line (southbound side)	90
Gap between double centrelines	80
Barrier centre line (northbound side)	80
Northbound lane	3270
Northbound edge line	130
Northbound shoulder	920

Table 2.5 Retro-reflectivity measured at Site P2

Direction	Centreline (mcd/lx/m²)	Edge line (mcd/lx/m²)
Northbound	234	No data
Southbound	119	No data

2.4.3 Site P3: Great Southern Highway – SLK 111-112

Site P3 is located on the Great Southern Highway between SLK values of 111 and 112. The site has a broken centreline and audio-tactile edge lines. Both the centreline and edge lines were subjected to testing. A photograph of the site is shown in Figure 2.8 and the dimensions of the road are shown in Table 2.6. Retro-reflectivity was measured at two locations at this site and the average of these measurements is shown in Table 2.7.

Figure 2.8 Site P3, Great Southern Highway (SLK 111-112)

Table 2.6 Typical road dimensions measured at Site P3

Element	Width (mm)
Southbound shoulder	910
Southbound edge line	130
Southbound lane	3460
Centreline	100
Northbound lane	3450
Northbound edge line	130
Northbound shoulder	930

Table 2.7 Retro-reflectivity measured at Site P3

Direction	Centreline (mcd/lx/m²)	Edge line (mcd/lx/m²)
Northbound	210	153
Southbound	94	123

2.4.4 Site P4: Great Southern Highway – SLK 113-118

Site P4 is located on the Great Southern Highway between SLK values of 113 and 118. The site has a broken centreline and audio-tactile edge lines. Only the centre line was subjected to testing. A photograph of the site is shown in Figure 2.9 and the dimensions of the road are shown in Table 2.8. Retro-reflectivity was measured at one location at this site and is shown in Table 2.9. The low retro-reflectivity in the Northound direction was suggested by the experts from Main Roads to be the result of the marking being painted too fast, or a paint-gun not being configured correctly.

The effect of applying water to the centreline was also assessed at this site.

Figure 2.9 Site P4, Great Southern Highway (SLK 113-118)

Table 2.8 Typical road dimensions measured at Site P4

Element	Width (mm)
Southbound shoulder	1020
Southbound edge line	130
Southbound Lane	3500
Centreline	90
Northbound Lane	3440
Northbound edge line	120
Northbound Shoulder	1000

Table 2.9 Retro-reflectivity measured at Site P4

Direction	Centreline ($mcd/lx/m^2$)	Edge line ($mcd/lx/m^2$)
Northbound	57	No Data
Southbound	137	No Data

2.4.5 Site P5: Great Southern Highway – SLK 133-134

Site P5 is located on the Great Southern Highway between SLK values of 133 and 134. The site has a broken centreline and audio-tactile edge lines over a darkened bitumen shoulder. Only the edge lines were subjected to testing. A photograph of the site is shown in Figure 2.10 and the dimensions of the road are shown in Table 2.10. Retro-reflectivity was measured at one location at this site and is shown in Table 2.11.

Figure 2.10 Site P5, Great Southern Highway (SLK 133-134)

Table 2.10 Typical road dimensions measured at Site P5

Element	Width (mm)
Southbound shoulder	920
Southbound darker shoulder encroaching to lane	540
Southbound edge line	140
Southbound lane	3380
Centreline	100
Northbound lane	3410
Northbound darker shoulder encroaching to lane	490
Northbound edge line	140
Northbound shoulder	1020

Table 2.11 Retro-reflectivity measured at Site P5

Retro-reflectivity	Centreline (mcd/lx/m²)	Edge line (mcd/lx/m²)
Northbound	No Data	119
Southbound	No Data	156

2.4.6 Site A1: Great Southern Highway – SLK 148-150

Site A1 is located on the Great Southern Highway between SLK values of 148 and 150. The site has a broken centreline and audio-tactile edge lines.

This site was identified by the field-work team as a site for investigation as, in their opinion, it had poor centreline visibility in a Northbound direction, but reasonable centreline visibility in a Southbound direction. The team also noticed that the trial vehicle had trouble identifying the line as they drove along the site in a Northbound direction, particularly in the late afternoon.

Only the centreline was subjected to testing. A still taken from the recorded video data is shown in Figure 2.11. No site dimensions were recorded, and retro-reflectivity was not measured.

Figure 2.11 Recorded images of centrelines at Site A1 showing Northbound (left) and Southbound (right) travel

2.4.7 Site A2: Wickepen-Pingelly Road

Site A2 is located on Wickepen-Pingelly road, immediately East of the township of Pingelly. The site has a broken centreline and is without edge lines.

This site was identified by the field-work team as a site for investigation as one trial vehicle occasionally identified and provided a warning for the edge of the road.

Only the edge of road was tested. A photograph of the road is shown in Figure 2.12. The dimensions are shown in Table 2.12. Retro-reflectivity was not measured.

The effect of applying water to the edge of the road (in an attempt to create a edge line) was assessed at this site.

Figure 2.12 Site A2, Wickepen-Pingelly Road

Table 2.12 Typical road dimensions measured at Site A2

Element	Width (mm)
Westbound width of gravel	1000
Westbound lane	3600
Broken centreline	90
Eastbound lane	3710
Eastbound width of gravel	600

2.4.8 Site A3: Brookton Highway

Site A3 is located on the Brookton Highway, immediately West of the township of Brookton. The site has a length of approximately six kilometres and includes sections of road within the Brookton township. The site has many varied road markings as shown in Figure 2.13.

Figure 2.13 Recorded images at Site A3 showing edge lines in the town centre (top left); pseudo edge lines (top right); dark bitumen shoulder (bottom left); and light bitumen shoulder (bottom right)

This site was identified by the field work team as a site for investigation for a number of reasons. First, a portion of the site had road markings that were formed as a result of bitumen repair work. These were termed ‘pseudo lines’. Second, there were solid edge lines in the town that appeared to the field-work team to result in warning failures by the LDW system. Third, there were various other road markings outside of the town that could be tested in a single run. These included an absence of edge line; solid edge lines; bitumen shoulders without edge lines but with either a lighter or darker shade of bitumen from the road surface. Fourth, because the site had an East-West orientation, the effect of driving into the sun in the late afternoon could be tested. The centrelines, being either a broken centreline, or a broken-barrier type centreline were tested during these times of sun glare. Screen shots from the sun glare situations are shown in Figure 2.14.

The dimensions of the portion of the road with pseudo lines are shown in Table 2.12. Retro reflectivity was not measured.

Figure 2.14 Sun glare on a broken barrier type line (left) and broken centreline (right) at Site A3

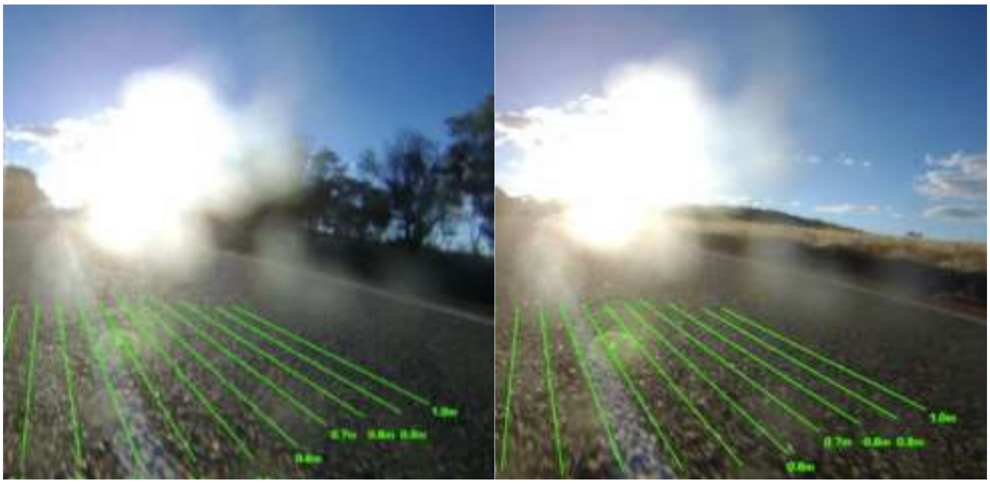


Table 2.13 Typical road dimensions measured at Site A3

Element	Width (mm)
Width of road	7400
Width of pseudo lines	200-300

2.4.9 Site A4: Howard St, Popanyinning

Site A4 is located on Howard Street in Popanyinning. The site has no centreline and is without edge lines. This site was identified by the field-work team as a site for investigation because it was a narrow road without a centreline or edge lines. The road has a width of approximately 3800 mm. Only the edge of road was tested.

2.5 Data processing and statistical analysis

The data processing was performed after all of the data collection had been completed.

All video footage was viewed by an independent researcher, who was not a member of the field-work team, and the details of all crossing events were catalogued in a custom database. The variables coded included the travel speed (as measured by the GPS equipment), time of day, whether a warning was activated (i.e. positive or negative result), and distance between the tyre and the line when a warning was activated.

Temperature, daylight brightness data, and which trial vehicle was driven were recorded in the database for each run. Sun glare and water-on-road variables were also recorded for each run.

GPS data was stored separate to the database and used to derive maps of the sites.

Statistical analysis of the data consisted of determining the percentage of correctly activated warnings (warning accuracy) by the two LDW systems in response to crossing events conducted with the various line markings. Warning accuracy was disaggregated by centreline data, edge line data, and edge of road (without a marked line) data. Data for each of the trial vehicles was considered separately.

Further disaggregation of warning accuracy was performed for the different line types, retro-reflectivity, daylight brightness, sun glare and water

-on-road. Graphical analysis of warning rates based on travel speed was also performed.

2.6 Risk assessments and safe operating procedures

Separate risk assessments were performed for the three major on-road activities performed during this study. These activities were:

- Driving to, from, and between trial sites;
- Performing the evaluation at each trial site; and
- Conducting the LDW trials at each test location.

These risk assessments (shown in Appendix A) were initially generated by researchers at CASR then subsequently reviewed by project stakeholders at C-MARC and

MRWA. Based on the risk assessments, a safe operating procedure was then developed for the field-work team to follow when conducting each activity.

2.7 Ethics approval

Ethics approval was not required for this study as it did not directly involve human subjects.

3 RESULTS

3.1 A typical warning

For Vehicle A, a typical warning occurred when the edge of the tyre first touched the edge of a line. Reviews of the recorded video indicated that an audible warning occurred before a visual warning on the dashboard. The time between the audible warning and the visual warning was approximately 0.3 seconds. For this vehicle, the visual system used during the testing provided an on-dashboard diagram indicating when the system detected the presence of a lane line, and which lane line (left or right) it had detected. When a warning occurred, the visual system indicated the side of the warning with a flashing line.

For Vehicle B, as for Vehicle A, a typical warning occurred when the edge of the tyre first touched the edge of a line. An audible warning occurred before the visual warning in this vehicle too, with a time difference of between 0.3 seconds and 0.5 seconds. Unlike Vehicle A, no indication of line observation was made to the driver. In this vehicle, the visual warning indicated the side of the warning by flashing a line on an on-dashboard diagram.

3.2 Explanation of result tables

In most of the tables that follow the data is shown in the form:

$$x/y\ (z\%)$$

Where:

- x is the total number of positive warning activations
- y is the total number of crossing events
- z% is the percentage of positive activations (i.e. $z = x/y \times 100\%$)

3.3 Provision of all crossing event results

Appendix B contains the details of all crossing events in tables split into marked centrelines, marked edge lines, and unmarked edge of road.

3.4 Total crossing events and warning accuracy

As shown in Table 3.1, there were 189 crossing events from which data was collected; 74 of these occurred with Vehicle A, 115 occurred with Vehicle B. Overall, the warning accuracy with both vehicles was consistent at between 81% (n=61/74) and

82% (n=93/115). Further explanation of the 35 warning failures that occurred are provided in the sections that follow, but include crossing events on roads without edge lines and crossing events at low travel speeds; both of which are known to be beyond the capabilities of the LDW systems used in this study.

Table 3.1 Warning activations for lines tested

Line type	Vehicle A	Vehicle B	Total
Total crossing events	74	115	189
Accurate warnings	61	93	154
Warning accuracy	82%	81%	81%

3.5 All crossing events by line class

The warning activations, total crossing events, and warning accuracy for each vehicle are disaggregated according to the class of line which was being tested are shown in Table 3.2. The accuracy was above 85% for the marked centrelines and marked edge lines. The table shows that unmarked road edges have lower warning accuracy rate; 25% for Vehicle B and 62% for Vehicle A.

Table 3.2 Warning activations for lines tested

Line type	Vehicle A	Vehicle B	Total
Marked centreline	35/40 (88%)	59/59 (100%)	94/99 (95%)
Marked edge line	16/17 (94%)	28/32 (88%)	44/49 (90%)
Unmarked road edge	10/17 (59%)	6/24 (25%)	16/41 (39%)
Total	61/74 (82%)	93/115 (81%)	154/189 (81%)

3.6 All crossing events by site

The warning activations, total crossing events, and warning accuracy for each vehicle are disaggregated according to trial site in Table 3.3 and Table 3.4. Table 3.3 shows the data for the planned sites, and Table 3.4 shows the data for the ad-hoc sites. From the planned sites, there were only 4 warning failures. Three of these failures occurred at site P4, where the retro-reflectivity of the centreline was found to be low, at times when the daylight brightness was low. The reason for the fourth failure, on an edge line at site P5, is unknown.

At the ad-hoc sites there were many warning failures. The high number of warning failures at the ad-hoc sites was not unexpected as these sites were deliberately chosen to test the limitations of LDW system capability in conditions where the manufacturers had warned of poor performance. At site A1, where the centreline was observed by the field-work team to be difficult to see in one direction, there were two failures. While the overall warning accuracy of the unmarked road edge assessments at sites A2 and A4 was poor, there was still a surprising number of successful warnings. At site A3, a significant number of the successful warnings were triggered during a crossing event at a pseudo line.

Table 3.3 Warning activations at each planned site

Site	Vehicle A	Vehicle B	Total
P1	6/6 (100%)	5/5 (100%)	11/11 (100%)
P2	8/8 (100%)	12/12 (100%)	20/20 (100%)
P3	15/15 (100%)	17/17 (100%)	32/32 (100%)
P4	10/13 (77%)	17/17 (100%)	27/30 (90%)
P5	6/6 (100%)	10/11 (91%)	16/17 (94%)
Total	45/48 (94%)	61/62 (98%)	106/110 (96%)

Table 3.4 Warning activations at each ad-hoc site

Site	Vehicle A	Vehicle B	Total
A1	2/4 (50%)	13/13 (100%)	15/17 (88%)
A2	3/5 (60%)	4/12 (33%)	7/17 (41%)
A3	10/14 (71%)	15/23 (65%)	25/37 (68%)
A4	1/3 (33%)	0/5 (0%)	1/8 (12%)
Total	16/26 (62%)	32/53 (60%)	48/79 (61%)

3.7 Line Type

The warning activations for each vehicle, disaggregated by line type, are shown in Table 3.5 to Table 3.7. Table 3.5 is the data for the centrelines, Table 3.6 is the data for the edge lines, and Table 3.7 is the data for the edge of road, without an edge line.

For the centreline data, all five warning failures occurred on a broken centreline with Vehicle A. Two of these negative warnings occurred at site A1 when travelling in a Northbound direction which involved a line identified by the field-work team as being difficult to see. The other three occurred at site P4 where the retro-reflectivity of the centreline and daylight brightness levels were both low.

For the edge line data, several warning failures occurred on solid edge lines for both trial vehicles. All these warning failures occurred while the vehicles were travelling below the listed operational speed of the LDW systems. There was also one failure, for Vehicle B, on an audio-tactile edge line and dark shoulder. The reason for this failure remains unknown.

The majority of crossing events that occurred on unmarked road edges resulted in warning failures (as expected). However, there were still 11 successful warnings triggered. No explanation for the success or failure of a warning being triggered during a crossing event on an unmarked road edge was identified by either the field-work team or the researcher reviewing the collected video footage.

There was a 100% warning rate for crossing events that occurred on pseudo lines near the edge of the road for both Vehicle A and Vehicle B. This reveals that ‘line-type’ markings such as this can readily deceive LDW systems. It also indicates that the contrast between line markings and road surface is an important factor in the operation of LDW systems.

Table 3.5 Warning activations for marked centrelines

Line type	Vehicle A	Vehicle B	Total
Barrier-Broken	4/4 (100%)	6/6 (100%)	10/10 (100%)
Broken centreline	20/25 (80%)	39/39 (100%)	59/64 (92%)
Broken-Barrier	5/5 (100%)	9/9 (100%)	14/14 (100%)
Double Barrier	6/6 (100%)	5/5 (100%)	11/11 (100%)
Total	35/40 (88%)	59/59 (100%)	94/99 (95%)

Table 3.6 Warning activations for marked edge lines

Line type	Vehicle A	Vehicle B	Total
Solid edge line	0/1 (0%)	5/8 (62%)	5/10 (50%)
Audio-tactile edge line and dark shoulder	6/6 (100%)	10/11 (91%)	16/17 (94%)
Audio-tactile edge line	10/10 (100%)	13/13 (100%)	23/23 (100%)
Total	16/17 (94%)	28/32 (88%)	44/49 (90%)

Table 3.7 Warning activations for unmarked road edge, by edge type

Line Type	Vehicle A	Vehicle B	Total
None	7/14 (50%)	4/22 (18%)	11/36 (31%)
Pseudo solid edge line	3/3 (100%)	2/2 (100%)	5/5 (100%)
Total	10/17 (59%)	6/24 (25%)	16/41 (39%)

3.8 Travel Speed

The effect of travel speed is shown in Figure 3.1 to Figure 3.3 below. Figure 3.1 shows data for the marked centrelines, Figure 3.2 shows data for the marked edge lines, and Figure 3.3 shows data for the unmarked road edges.

For the centreline data, the crossing event travel speeds ranged between 70 km/h and 110 km/h. The five warning failures occurred at speeds between 100 km/h and 110 km/h. The travel speed did not appear to have any effect on the ability of the LDW system to correctly identify the line marking.

For the marked edge lines, the speeds ranged between 30 km/h and 110 km/h. Five of the warning failures occurred at speeds below the manufacturer's advised minimum speed for system operation. A specific reason for the one warning failure that occurred at a speed above the manufacturer's advised minimum speed could not be identified.

For the unmarked road edge data, the speeds ranged between 40km/h and 85 km/h. Warning failures occurred both above and below the minimum recommended speed. The majority of successful warnings occurred at speeds above the minimum recommended speed,

Figure 3.1 Crossing event travel speeds for marked centrelines

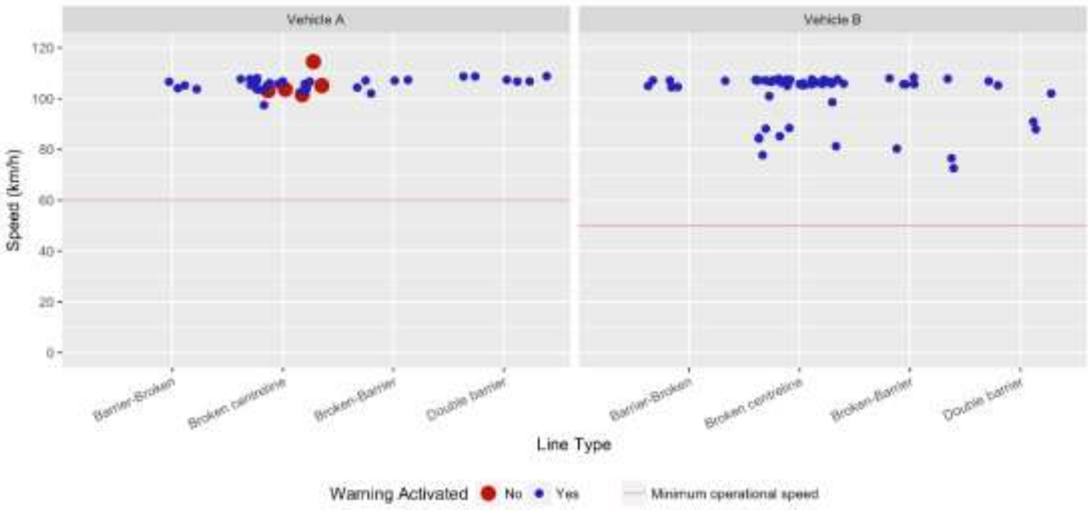


Figure 3.2 Crossing event travel speeds for marked edge lines

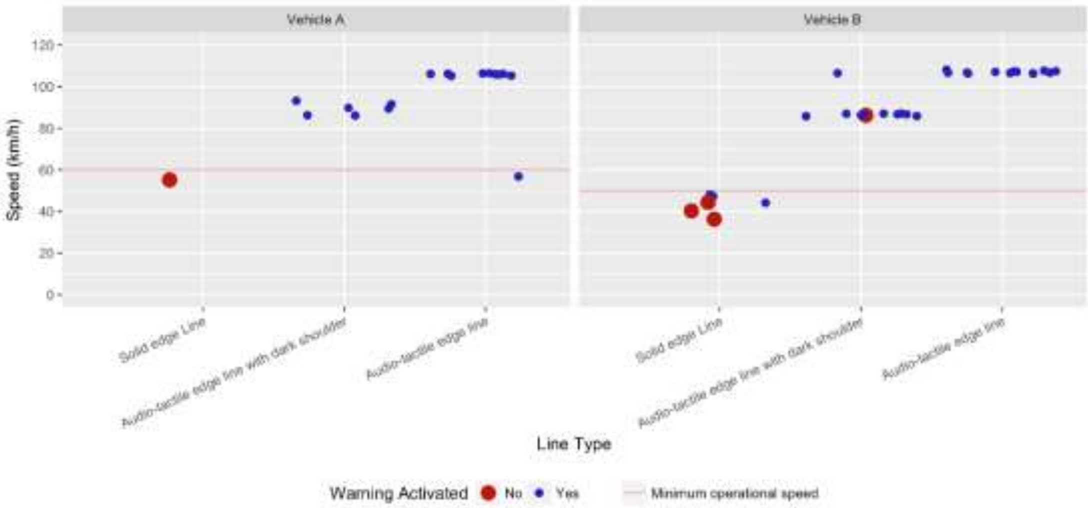
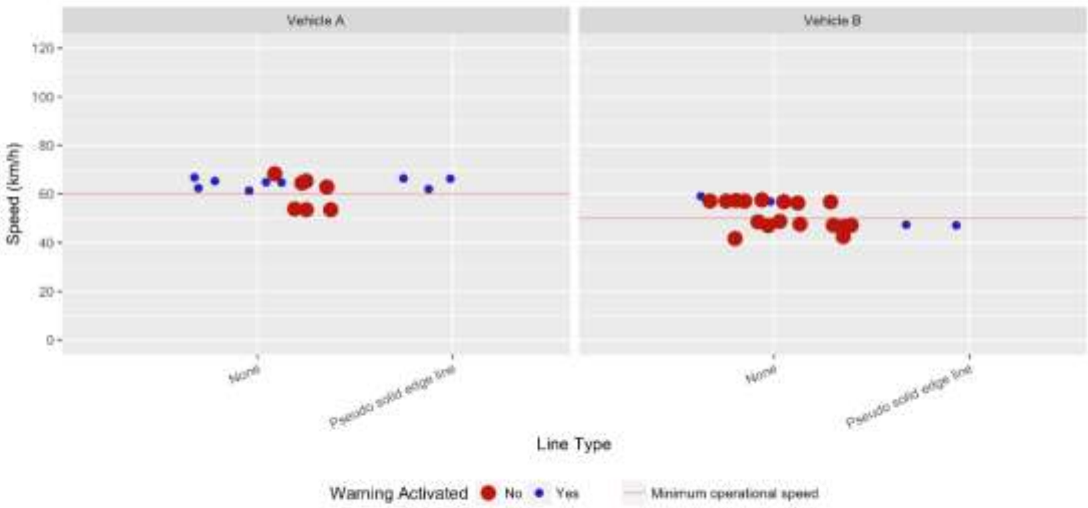


Figure 3.3 Crossing event travel speeds for unmarked road edges



3.9 Retro-reflectivity

Retro-reflectivity data was only collected at the five planned trial sites. The collected retro reflectivity levels ranged between a low of 57 mcd/lx/m² and a high of 234 mcd/lx/m². It was reported by the retro-reflectivity experts from Main Roads that, for WA, the minimum intervention level for retro-reflectivity is 100 mcd/lx/m², while most other states have moved to a level of 150 mcd/lx/m².

Table 3.8 and Table 3.9 shows the breakdown of warning activations for the differing stratified levels of retro-reflectivity on marked centrelines and marked edge lines, respectively.

Three warning failures occurred on the centreline at site P4; two in the Northbound direction where the retro-reflectivity was 57 mcd/lx/m² and one in the Southbound direction where the retro-reflectivity was 137 mcd/lx/m². It is important to note that these failures occurred while the level of daylight brightness was also low.

It is also worth noting that the remaining two warning failures on centrelines, where the retro-reflectivity was not measured, occurred at site A1 whilst travelling in a Northbound direction where the field-work team found it difficult to see the line.

There was only one waring failure for an edge line with a known retro-reflectivity level. This occurred at site P5 with a retro-reflectivity of 156 mcd/lx/m² but the specific reason for the failure was not clear.

The remaining four warning failures on marked edge lines (without a known retro-reflectivity) occurred while the vehicle was travelling below the manufacturer's advised minimum speed.

Table 3.8 Warning activations, by retro-reflectivity, for marked centrelines

Retro-reflectivity (mcd/lx/m²)	Vehicle A	Vehicle B	Total
>50 to75	7/9 (78%)	10/10 (100%)	17/19 (89%)
>75 to 100	-	-	-
>100 to 125	8/8 (100%)	14/14 (100%)	22/22 (100%)
>125 to 150	3/4 (75%)	7/7 (100%)	10/11 (91%)
>150 to 175	-	-	-
>175 to 200	-	-	-
>200 to 225	7/7 (100%)	1/1 (100%)	8/8 (100%)
>225 to 250	4/4 (100%)	6/6 (100%)	10/10 (100%)
Not measured	6/8 (75%)	21/21 (100%)	27/29 (93%)
Total	35/40 (88%)	59/59 (100%)	94/99 (95%)

Table 3.9 Warning activations, by retro-reflectivity, for marked edge lines

Retro-reflectivity (mcd/lx/m²)	Vehicle A	Vehicle B	Total
>100 to 125	10/10 (100%)	10/10 (100%)	20/20 (100%)
>125 to 150	-	-	-
>150 to 175	6/6 (100%)	13/14 (93%)	19/20 (95%)
Not measured	0/1 (0%)	5/8 (62%)	5/9 (56%)
Total	16/17 (94%)	28/32 (88%)	44/49 (90%)

3.10 Daylight brightness

The measured daylight brightness ranged from a low of 4,600 lux to a high of 130,000 lux. A value of 110,000 lux is typically considered to be direct sunlight on a sunny day, while a value 20,000 lux would be expected in a shaded area at noon on a sunny day. A dark overcast day would result in a brightness of around 2,000 lux.

As shown in Table 3.10, three warning failures occurred during crossing events on centrelines while the daylight brightness was below 50,000 lux. In each of these cases the retro-reflectivity of the centreline was also low. A further two warning failures on centrelines occurred when the daylight brightness was between 50,000 and 75,000 lux. Both these failures occurred at site A1 where the field-work team noted that the centreline was difficult to see.

In Table 3.11 the daylight brightness levels associated with crossing events performed on marked edge lines is shown. Two warning failures were observed when the daylight brightness was below 25,000 but these occurred while the vehicles was travelling below the manufacturer's advised minimum speed. A specific reason for the warning failure that occurred with a daylight brightness between 25,000 and 50,000 lux could not be identified as the edge line being crossed had a high retro-reflectivity. The remaining two warning failures during marked edge line crossings occurred with higher levels of daylight brightness but were likely the result of the vehicle travelling below the manufacturer's advised minimum speed.

Table 3.10 Warning activations, by brightness, for marked centrelines

Brightness (lux x1000)	Vehicle A	Vehicle B	Total
>1 to 25	1/3 (33%)	12/12 (100%)	13/15 (87%)
>25 to 50	5/6 (83%)	13/13 (100%)	18/19 (95%)
>50 to 75	4/6 (67%)	17/17 (100%)	21/23 (91%)
>75 to 100	25/25 (100%)	17/17 (100%)	42/42 (100%)
>100 to 125	-	-	-
>125 to 150	-	-	-
Total	35/40 (88%)	59/59 (100%)	94/99 (95%)

Table 3.11 Warning activations, by brightness, for marked edge lines

Brightness (lux x 1000)	Vehicle A	Vehicle B	Total
>1 to 25	-	3/5 (60%)	3/5 (60%)
>25 to 50	-	10/11 (91%)	10/11 (91%)
>50 to75	6/6 (100%)	13/13 (100%)	19/19 (100%)
>75 to 100	10/10 (100%)	2/3 (67%)	12/13 (92%)
>100 to 125	-	-	-
>125 to 150	0/1 (0%)	-	0/1 (0%)
Total	16/17 (94%)	28/32 (88%)	44/49 (90%)

Table 3.12 Warning activations, by brightness, for unmarked road edges

Brightness (lux x1000)	Vehicle A	Vehicle B	Total
>1 to 25	-	-	-
>25 to 50	-	0/5 (0%)	0/5 (0%)
>50 to75	1/3 (33%)	4/12 (33%)	5/15 (33%)
>75 to 100	-	2/7 (29%)	2/7 (29%)
>100 to 125	3/5 (60%)	-	3/5 (60%)
>125 to 150	6/9 (67%)	-	6/9 (67%)
Total	10/17 (59%)	6/24 (25%)	16/41 (39%)

3.11 Sun glare

The warning activations associated with and without the presence of sun glare are shown in Table 3.13. There were no warning errors on any of the events that were deliberately timed to coincide with sun glare. However, these assessments were performed in an ad-hoc fashion and should not be considered as a conclusive indication that LDW systems are immune to the effects of sun glare.

The effect of sun glare was not assessed during crossing events involving edge lines. Two events occurred with sun glare on a road without an edge line and neither resulted in a positive warning being triggered.

Table 3.13 Warning activations for centreline sun glare scenarios.

Sun glare	Vehicle A	Vehicle B	Total
No	31/36 (86%)	51/51 (100%)	82/87 (94%)
Yes	4/4 (100%)	8/8 (100%)	12/12 (100%)
Total	35/40 (88%)	59/59 (100%)	94/99 (95%)

3.12 Water on Road

Due to the ambient temperature on the days when the on-road trials were occurring, the water that was applied to the road did not persist for a significant period. As such, when the video footage was reviewed, it was difficult (though not completely impossible) to detect the water on the road.

Nonetheless, when water was placed on the centrelines of the road there were no warning errors for any of the crossing events, as shown in Table 3.14. Just one crossing event occurred with water on the edge of a road without an edge line. No warning was triggered for this event. No data was collected with water on a marked edge line.

Table 3.14 Warning activations for marked centreline water-on-road scenarios

Water on the road	Vehicle A	Vehicle B	Total
No	31/37 (84%)	54/54 (100%)	84/89 (94%)
Yes	4/4 (100%)	6/6 (100%)	10/10 (100%)
Total	35/40 (88%)	59/59 (100%)	94/99 (95%)

3.13 Summary

Overall, 189 crossing events were measured in the data sample. Of these, 154 (81%) gave an accurate warning, with a total of 35 (19%) warning failures.

At the planned sites, all of which were located on the Great Southern Highway, there were four warning failures from a total of 110 crossing events. This is a warning accuracy rate of 96%. At the ad-hoc sites, which were chosen because some warning errors were expected, 48 out of 79 of crossing events gave an accurate warning for an accuracy rate of 61%.

Overall, marked centrelines had the highest warning accuracy in the data set (95%). Marked edge lines also had a high accuracy rate (90%). Unmarked road edges had the lowest accuracy rate (39%).

The 35 warning failures that were encountered can be attributed in the following way:

- 12 occurred where there was absence of a marked line;
- 4 occurred when the travel speed was below than the manufacturer recommended speed for system operation;
- 13 occurred in the absence of a marked line along with the travel speed being below than the manufacturer recommended speed;
- 5 occurred when retro-reflectivity and daylight brightness levels were both low, or the field-work team noted they had trouble seeing the line; and
- 1 warning failure was unexplained.

The one unexplained warning failure occurred on an audio-tactile edge line. It occurred at 4:25 in the afternoon, travelling Southbound at site P5. The shadow of roadside trees was being cast onto the road at the location on the warning failure (although this was also true of many other crossing events). Review of the video data showed that at maximum crossing, only half of the line width had been crossed over by the vehicle wheel. Whilst it is possible that a warning was not generated because of this short crossing distance, review of the video showed another event on the same run with a similar crossing distance where an accurate warning did occur.

In summary, the LDW systems performed as expected when tested on roads with lane markings in reasonable condition. Failures of the LDW systems occurred on roads without lane markings or when the vehicle speed was lower than that specified by the manufacturer for proper system operation. There were several failures that were attributed to poor daylight brightness combined with a line marking that had poor retro-reflectivity or was noted as difficult to see by the field-work team. It was also discovered that longitudinal pseudo line markings would reliably result in warnings by LDW systems.

4 DISCUSSION

The aim of this investigation was to undertake an on-road trial of the positional sensitivity of LDW systems when presented with typical line markings found on rural WA roads.

Three days of on-road testing of the lane departure warning systems of two vehicles on six sections of the Great Southern Highway and three sections of road travelling East or West of this road was undertaken. All of the testing was completed in the vicinity of the towns of Brookton, Pingelly, Popanyinning and Cuballing.

Video footage and GPS data was recorded during the on-road testing. This data was subsequently reviewed, and 189 crossing events were processed for further analysis. Of the 189 crossing events, 154 (81%) were associated with an accurate warning. The remaining 35 (19%) failed to trigger a warning.

4.1 Theory of operation

While an investigation into the specific details of operation for LDW systems was beyond the scope of this study, it is still important to outline the general theory of operation in order to provide context to the discussion that follows.

Based on the authors understanding, and the experiences of the field-work team, the LDW systems used in this study operated in the following way:

- In-vehicle sensors with a view out the front of the vehicle gather information about the road environment;
- This road data is processed and any line markings in the field of view are identified;
- The lateral position of the vehicle, relative to the lines, is then calculated by the system;
- A crossing event is predicted by the system when the lateral position of the vehicle intersects with a line marking; and
- A warning is then signalled to the driver via a buzzer and dashboard indicator.

It is important to note that the LDW system does not have a direct view of the vehicle's wheels or their position relative to any line marking. The lateral position of the vehicle is thus calculated based on either extrapolation of the viewed line, or forward projection of the vehicle motion (e.g. expected future position based on current position of the steering wheel).

4.2 Accurate warnings

The majority of crossing events at the planned sites, where line markings were present and maintained, resulted in accurate warnings (96%, n=110). This was true for both centrelines (96%, n=70) and edge lines (98%, n=40).

Audio-tactile edge lines with dark shoulders encroaching onto the road way (encountered at site P5) did not affect the accuracy of the LDW systems. This is interpreted as a favourable result as it indicates that roadside shoulder sealing can be applied without concern that it will limit the effectiveness of lane support technologies.

There was also no affect of LDW accuracy when water was applied to the centrelines at site P4. However, it was noted that the hot temperature and sunny conditions may have limited the impact of the water during the assessments.

While the warning accuracy rate the at ad-hoc sites was low (61%, n=79), there were a number of accurate warnings that were triggered under interesting conditions.

At site A3 several pseudo lines were formed along the road due to a darker coloured bitumen being used when repairing the bitumen roadway. These pseudo lines had a width of between 200 and 300 mm, compared to a standard painted edge line width of 120 mm. Nonetheless, the pseudo lines reliably triggered warning activations in both LDW systems (100%, n=5). This is suggestive that a contrasting, longitudinal marking along the roadway of an appropriate width will result in warnings that may not be warranted. This was deemed unlikely to have an adverse outcome at site A3 but may be cause for some concern in other locations, particularly where a pseudo line was to veer off the roadway or continue in a straight line through a curve. Lane support systems which manipulate the steering, such as lane keeping assist, could become confused by such pseudo lines and may steer a vehicle out of the nominal lane position or even off the road completely.

The reliable activation of warnings during pseudo line crossing events also indicates the importance of contrast between the colour of line markings and the underlaying roadway. While the retro-reflectivity of the pseudo lines was not measured, it is likely to be low compared to a painted line marking. This is suggestive that contrast may be more important than retro-reflectivity to the correct operation of the camera based LDW systems that were used in this study.

Accurate warnings sometimes occurred on the edge of an unmarked road (31%, n=36). However, this was unreliable and was not listed as a capability by either of the LDW systems used in this study. It may be that accurate warnings were more likely to occur on road edges when there were high levels of contrast between the road surface and the road verge, but this was not measured and so cannot be investigated.

As the capabilities of lane support technologies improve over time it is likely that their effectiveness in accurately responding to unmarked road edges will improve. The assessment of what type of road edge is required for the effective operation of those systems may then be appropriate.

4.3 Warning failures

There were 35 warning failures observed during the study. The majority of warning failures (29) occurred where the was absence of a marked line (31%, n=36) and/or when the crossing event travel speed was less than the manufacturer's recommended speed for system operation (24%, n=21). These circumstances were declared limitations of the LDW systems on the trial vehicles that were used in the study (as described in Section 2.1). As such, it is unreasonable to expect that the LDW systems would give accurate warnings in these circumstances. At the sites where a line marking was absent, it would be expected (based on the outcomes of this study) that the addition of a suitable line marking will be sufficient to enable the reliable operation of LDW systems. Where the travel speed was too low, this is a limitation of the currently available lane departure warning systems, and may be rectified by regulation, legislation, manufacturer competition, or consumer demand. Alternative safety measures may also be more appropriate in low speed areas, such as infrastructure like kerbing. It is expected that, as the LDW technology advances, the minimum recommended speed for operation will decrease and the effectiveness with unmarked road edges will improve.

There were 3 warning failures observed in circumstances where both the daylight brightness level and line marking retro-reflectivity were low. Two warning failures occurred on a line marking with a retro-reflectivity of 57 mcd/lx/m² and one occurred on a line marking with a retro-reflectivity of 137 mcd/lx/m². The daylight brightness levels at the time of the warning failures were representative of an overcast day, though not excessively dark.

Experts from Main Roads reported that the minimum intervention level for retro-reflectivity is 100 mcd/lx/m² in WA, but that most other states have moved to a level of 150 mcd/lx/m². They expressed surprise at the measured retro-reflectivity level of 57 mcd/lx/m² and suggested that the marking may have been painted too fast, or that the paint-gun was not configured correctly.

Given the warning failures, it would seem appropriate to maintain the practice of addressing line markings if their retro-reflectivity level falls below 100 mcd/lx/m² and consider observing the higher level of 150 mcd/lx/m² being used in other Australian states.

A further 2 warning failures occurred during crossing events involving a centreline that was noted by the field-work team as being difficult to see (the retro-reflectivity was not measured). This is further indication that line marking contrast may be important for the effective functioning of lane support technologies.

The reason(s) for the final unexplained warning remain unknown and could not be categorised. It is possible that the LDW system failed in detecting the line or in detecting the crossing. However, it is also possible that the system made an active decision to not provide a warning due to the shallowness of the line crossing. This would need to be studied further with more test cases before a definitive explanation could be concluded.

4.4 Study limitations

By design, the scope of the study was limited to be an observational study conducted over three days.

Some of the sites were pre-planned and these were selected to enable assessment of a cross section of the lane markings that could be encountered on a rural WA highway. These sites were also selected because they were on a relatively low trafficked highway and not too far from a major city centre, so they may not be representative of all rural WA roads. They also may have been maintained better than other sites in more isolated areas of WA which may explain the high accuracy warning. The ad-hoc sites were chosen during the field-work portion of the study. These were chosen because the field-work team felt that they may provide some interesting or unusual results such as difficult to see centrelines, various types of unmarked road edge, pseudo line markings, and the opportunity to drive towards sun glare.

As a consequence of this mix of pre-planned and ad-hoc sites, conducted over a three-day period, there was minimal variation in the types of road chosen which may have also limited the generalisability of the study results. It is not possible to determine from the data, for example, the threshold characteristics of the line markings at which they change from being compatible with lane departure warning systems, to incompatible.

The study design did not allow for observation of the line markings in conditions other than daylight. While some late-afternoon testing was completed, no testing was done in conditions that resembled dusk, night time, or dawn.

The on-road trial was conducted exclusively on single lane, undivided roads. No data was collected on dual lane roads, overtaking lanes, or on roads with roadside infrastructure, such as crash barriers.

Finally, the study was done within a small geographical area. This limits the applicability of the study to the small sections of road that were studied. This project was not an audit of all WA roads and cannot indicate the quality of the line markings on the roads that were not tested.

4.5 Conclusion

The findings of this study show that LDW systems are capable of providing appropriate warnings in rural road environments when there are suitable line markings. It was clear that the line markings being utilised on WA roads, where they have been well maintained to provide sufficient levels of contrast with the road surface and retro-reflectivity, comfortably meet this level of suitability. This was true regardless of line marking type (see Table 2.1).

Despite this general finding, there were several situations where warnings failed to trigger. In most cases, the situations leading to these failures were noted as limitations in the LDW system user manuals and not the road infrastructure.

While it was not possible to determine a quantitative definition of a suitable line marking, there were some indications of what may be important. The level of retro-reflectivity, combined with the level of available daylight brightness, did appear to indicate where LDW systems may have difficulty in detecting a line marking. There was also an indication that line marking visual contrast is important to consider.

5 RECOMMENDATIONS

5.1 Maintain an adequate maintenance regime for rural highway line markings

This report has highlighted that, in general, vehicles equipped with lane departure warning systems or lane keep assist systems operate reliably with the line markings applied onto the Great Southern Highway. It is assumed that these line markings are broadly similar to other line markings throughout the rural WA road network. Although it is acknowledged that the maintenance of line markings may not be performed to the same standard on all roads, particularly those in remote areas.

However, there were a number of warning failures at sites where the retro-reflectivity of line markings were found to be below the suggested minimum of 100 mcd/lx/m^2 or where the field-work team had difficulty seeing the line. These events were highlighted in Section 3.9. For future compatibility between the road network and vehicles equipped with lane support systems the lines of the road network must be maintained above these levels and consideration given to adopting a minimum retro-reflectivity level of 150 mcd/lx/m^2.

5.2 Increase the proportion of the road network with lane markings

This report has shown that the absence of lane markings is incompatible with LDW systems. For universal compatibility to be achieved, all bituminised roads in the WA road network will need edge and centreline lane markings.

5.3 Avoid road maintenance that results in the creation of pseudo lines

It was shown, particularly at Site A3, that repair/maintenance works which create pseudo lines along the road can deceive a LDW system into responding to those markings. This type of response to pseudo lines was also noted in the user manual of both the vehicles used in this study as a limitation.

Road maintenance that produces this type of pseudo line should be avoided (and rectified where possible) as it can result in sections where LDW systems may not operate reliably. Furthermore, technologies that manipulate the steering wheel in response to line markings may erroneously manoeuvre a vehicle out of the correct lane in response to pseudo lines.

5.4 Provide sufficient space for recovery

The warnings provided by the LDW systems assessed in this study were triggered as the vehicle travelled across a line marking. When a driver, who may be distracted or fatigued, receives a warning they will require some period of time to respond and take corrective action. During this response time, their vehicle will continue to travel past the line marking and towards the edge of the road.

The provision of appropriately wide sealed roadside shoulders (or wider gap between barrier centre lines where appropriate) will enable drivers to successfully recover their vehicle in response to a lane departure warning.

5.5 Future research

While the current study has resulted in a number of findings, there were also several limitations (as discussed in Section 4). To overcome some of these limitations, a program of future research is recommended. Five potential projects are suggested below.

5.5.1 Audit of line marking suitability

Vehicle A, as used in this study, had a dashboard display screen that indicated to the driver whether the lane keeping assist was active, or otherwise. As part of this display, the system also indicated which of the lane markings (left or right) were being actively detected. It may be possible to use this dashboard display, combined with GPS position data, to complete a highway audit. A drive through of important sections of the WA road network, using a car with this equipment installed, would permit sections of the road where the lines are not visible to the lane keeping assist system to be identified.

5.5.2 Low light study

An unanswered question from the current study is the suitability of the line markings during overcast conditions as well as during night-time, daybreak, and twilight hours. An interesting extension would be to repeat the current study during these non-ideal lighting circumstances.

5.5.3 Quantification of line marking requirements

During the current study, retro reflectivity was measured at some of the sites. There are two limitations to this. First, the measurements taken were samples from much longer sections of road. Second, because camera-based lane departure warning systems were used in the study there may be other metrics which may be better suited to characterising the 'conspicuity' of the line. Examples of these other metrics include contrast or colour-difference between the line and its surrounding bitumen. A systematic study could be undertaken to artificially generate a number of different line and bitumen combinations with various contrasts and colours to identify the most relevant metric for line conspicuity. The study would subsequently identify the minimum thresholds for conspicuity that should be observed for LDW system accuracy.

5.5.4 Examination of system reliability where there is other infrastructure

Only lines marked on the road, in a consistent pattern, were considered in the current study. Absent from the analysis was other types of highway infrastructure. This includes locations where there are other markings on the road (e.g. information painted on the road in the middle of motor ways) or where there are crash barriers that run parallel to the road. Sections of road with infrastructure like this could be examined in a study with a similar methodology to the current one.

5.5.5 Investigation of the effect of departure angle

One consideration for this study was the investigation of the effect that departure angle has on the reliability of LDW. However, during the risk assessment process, the application of anything greater than a small departure angle while travelling at high speed was deemed unsafe. An alternative to an on-road trial would be to conduct this type of investigation on a test track, where higher departure angles could be applied in a safe manner.

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APPENDIX A

Risk assessments are shown below for the three project activities identified as dangerous:

- Driving to, from, and between trial sites;
- Performing the evaluation at each trial site; and
- Conducting the LDW trials at each test location.

These risk assessments were initially generated by researchers at CASR then subsequently reviewed by project stakeholders at C-MARC and MRWA. Based on the risk assessments, a safe operating procedure was then developed for the field-work team to follow when conducting each activity.

HAZARD MANAGEMENT – RISK ASSESSMENT(LONG FORM)

Stage 1:	**Hazard Identification**	**Residual risk rating L, M, H, VH**	M
Name or description of the activity(s) to be assessed	WA line marking and lane support systems (2018): Site surveying	**Date**:	13/02/2018
Area, School/Branch Building/Room	CASR/ECMS		
Workers completing the risk assessment. Name and contact details	MUNISH KUMAR	**Mobile/Phone**	0433 381 701
	ANDREW VAN DEN BERG	**Mobile/Phone**	08 8363 0555
	JAMIE MACKENZIE	**Mobile/Phone**	08 8313 7329

- This template or equivalent template can be used. Please note that this list is not exhaustive, but can be used as the basis for your initial hazard identification.
- If you tick yes to any of the hazards listed below, then the hazard is to be transferred and addressed on **Appendix C2.** Where a number of activities have the same hazards, they may be grouped together on the same assessment and the same control measures applied to each.

Consider – is there potential for, or identified exposure to any of the following, as part of a process/activity

	Physical/Environmental Hazards		**Plant and Equipment hazards**
☒	Animals (e.g. hazardous wild animals, bees, snakes)	☐	Mobile lifting equipment or farm machinery
☐	Confined space entry (e.g. pit, tank, silo, entry through a hatch)	☐	Pressurised vessels/systems (e.g. autoclave, boiler)
☐	Fall from a height (e.g. ladder, elevated platform, cliff, scaffolding)	☐	Hazardous levels of heat or vibration (to whole or part body)
☐	Fire (potential for uncontrolled fire due to ignition sources)	☐	Hazardous plant (e.g. lathes, lasers, microtomes, cryostats,
☒	Flying or moving items/plant/vehicles, falling object(s)		or operations could result in amputation, eye injury, serious
☒	Hazardous terrain or environment including wet/slippery surfaces		laceration, crushing injury)
☐	Lighting/visibility is compromised and hazardous		**Radiation hazards**
☐	Noise or sound levels > 85dB(A) or peak level of greater than	☐	Sealed sources or unsealed sources
	135 dB(C) for any period of time	☐	Artificial sources (UV)
☒	Temperature or weather extremes (e.g. hypothermia, major burns)		**Biological hazards (e.g. via inhalation, contact, digestion)**
☐	Isolation (e.g. work in a remote area, difficult to access work site,	☐	Contamination (e.g. pathogens, body fluids)
	or a rescue effort would be difficult in the event of an emergency.	☐	Animal handling (e.g. bites, allergies)
☐	Boating and/or Diving (e.g. risk of drowning)	☐	Other
	Communications		**Chemical hazards**
☐	Communication problems (e.g. by virtue of location or isolation)	☐	Explosive substances
	Electrical	☐	Flammable substances, gas, airborne contaminants
☐	Electric shock	☐	Toxic or asphyxiate gas (e.g. CO_2 including dry ice, liquid N_2)
	Ergonomic/Hazardous Manual activity/task(s)	☐	Respiratory irritants (e.g. nanotech, dust, asbestos)
☐	Work requiring repetitive force or movement	☐	Chemical spraying (e.g. agricultural, pesticides)
☐	Sustained force/posture or awkward posture	☐	Prohibited and restricted carcinogens requiring a permit
☐	Working with animals, unpredictable/unbalanced loads	☐	Hazardous chemicals (not included above)
☐	Transfer of item(s) up or down stairs, using both hands or	☐	Other
	requiring the use of lifting equipment from one level to another		**Activity combines a number of different hazards, and**
	Stress/Duress hazards		**the impact/results of interaction is unknown e.g. mixing**
☐	Personal threat e.g. aggressive behaviour, abuse, threat, assault		**chemicals or recognised as a risk e.g. water and electricity.**
	(includes home visits)	☐	Specify -
☐	Fatigue e.g. from excessive work related mental/physical exertion		**High Risk Travel**
	Remote work location or working in isolation	☐	Destination is rated DFAT 3 or 4 (High/Very High)
☐	Medical emergency, difficult to administer/obtain first aid		**High risk work licence required in accordance with WHS Regs**
	gain assistance e.g. access to medical facilities	☐	Boom-type elevating work platform, scaffolding, dogging,
	Other		crane and hoist operation, reach stackers, forklift operation,
☐			pressure equipment operation.
☐			
☐		☐	**No hazards identified. No risk assessment required.**

HAZARD MANAGEMENT

Stage 2 and Stage 3 – Risk Assessment and Control

Record the potential hazards/issues identified in Hazard Identification Process on Appendix C1 **and** **When and where the hazard is present (i.e. when is the worker exposed?)**	**Inherent risk assessment rating** Before controls are implemented (Refer to the risk assessment Tables – Appendix C3) **L, M, H, VH**	**List the control measures implemented (i.e. in place)** • Control measures are to be in accordance with the Hierarchy of Control. Refer to Appendix C3 for examples. • Choose the control(s) that most effectively eliminate the hazard or minimises the risk. • Record the control measures in place under the relevant control measure (e.g. list in order under the following headings - substitution, isolation, engineering, administrative, Personal Protective Equipment). • Ensure that control measures do not introduce new hazards.	**Residual risk rating** After controls in place The highest rating is to be transferred to the top of page C1.
Bushfire	**VH**	Admin –SMS text alerts from the WA Department of Fire and Emergency Services will be sent based on last known location of mobile phone. All CASR staff will carry mobile phones with location services switched on. If an alert for a nearby bushfire is received, CASR staff will depart and travel to a safe location.	**Medium**
Stings or bites due to contact with insects and animals	**M**	PPE – CASR staff will wear safety shoes, long pants, and long sleeved shirts. PPE – Insect repellent will be provided to CASR staff. Admin – CASR staff will avoid areas where there is long grass.	**Low**
Dehydration due to extreme temperature	**M**	Admin – Sufficient drinking water will be provided to CASR staff. Admin – CASR staff will remind one another to drink water throughout the day.	**Low**
Fatigue due to extreme temperature	**M**	Admin – Staff to check one another at regular intervals for signs of heat-exhaustion. PPE – CASR staff will wear long loose pants and a loose shirt with long sleeves. Admin – Regular breaks will be taken between working. Admin – A vehicle with air-conditioning will be available to provide relief from the heat.	**Low**
Hit by vehicle when performing site survey	**VH**	Admin – Roads being surveyed are low volume and there is good sight distance. Admin – Local region traffic management will be in attendance (with flashing beacons and road worker signs). Admin – CASR staff will follow instructions of local region traffic management. Admin – CASR staff will wear safety vests. Admin – Two CASR staff will undertake task (in addition to local region traffic management), with one person designated as a look out while the second performs the site survey.	**Medium**
Causing a crash by distracting other drivers	**VH**	Admin – Local region traffic management will be in attendance (with flashing beacons and road worker signs). Admin – CASR staff will follow instructions of local region traffic management. Admin – CASR staff will wear safety vests.	**Medium**
CASR vehicle creates a roadside hazard	**VH**	Isolation – The CASR vehicle will be parked in a safe location that is as far away from the edge of the road as possible	**Low**

HAZARD MANAGEMENT

RISK ASSESSMENT TABLES

Three essential steps are taken:
1. The probability or likelihood of an incident occurring is evaluated;
2. The severity of the potential consequences is calculated or estimated;
3. Based on these two factors, the risks are assigned priority for risk control through the use of a risk rating.

Risk assessment involves examining and evaluating the likelihood/severity/consequence in order to prioritise and implement adequate controls. The risk matrix has been adopted based on the principles of AS/NZS ISO 31000 (2009) Risk Management – Principles and Guidelines and Code of Practice "How to Manage Work Health and Safety Risks (2012).

Likelihood Table

CATEGORY	DESCRIPTION
Almost certain	There is an expectation that an event/incident will occur.
Likely	There is an expectation that an event/incident **could occur** but not certain to occur.
Slight	This expectation lies somewhere in the midpoint between "could" and "improbable".
Unlikely	There is an expectation that an event/incident is doubtful or **improbable** to occur.
Rare	There is no expectation that the event/incident will occur.

Consequences Table

CATEGORY	DESCRIPTION
Severe	Injury resulting in death, permanent incapacity.
Major	Injury requiring extensive medical treatment, hospitalisation, or activities could result in a Notifiable occurrence.
Moderate	Injury requires formal medical treatment (hospital outpatient/doctors visit etc), activities could result in an Improvement Notice.
Minor	Injury requires first aid.
Negligible	Injury requires minor first aid (e.g. bandaid), or result in short term discomfort (e.g. bruise, headache, muscular aches etc), no medical treatment.

Risk matrix

Likelihood	**Consequences**				
	Negligible	**Minor**	**Moderate**	**Major**	**Severe**
Almost Certain	Medium	High	Very High	Very High	Very High
Likely	Medium	Medium	High	Very High	Very High
Slight	Low	Medium	High	High	Very High
Unlikely	Low	Low	Medium	Medium	High
Rare	Low	Low	Low	Medium	Medium

<u>If the level of risk is assessed as high or very high</u>

- ❑ Stop the activity; or
- ❑ Tag out the plant/equipment; or
- ❑ Secure any chemical; and
- ❑ Determine if the activity is to:
  - ❑ continue; or
  - ❑ cease

in consultation with your Manager/Supervisor.

Follow the process in 3.5.6.1 where the risk cannot be reduced to medium or low.

HAZARD MANAGEMENT

HIERARCHY OF RISK CONTROL

Level of health and safety protection	Hierarchy of control		Examples of control measures	Reliability of control measures
HIGHEST	**Level 1**	**Elimination**	• Not introducing the hazard into the workplace. • Designing out the hazards before they are introduced. • Removing the hazard completely. • Not conducting the activity.	MOST
	If this is not practicable then	↓		
	Level 2 Where it is not reasonably practicable to eliminate the hazards and associated risks.	**Substitution**	• Replacing or substituting the hazard with something safer.	
		Isolation	• Isolating the hazard from the people by distance or using barriers.	
		Engineering	• Installing/using a control measure of a physical nature, including a mechanical device or process e.g. trolleys, hoists, guards, residual current devices, fume-hoods, extraction/ventilation systems, RCD protection.	
		↓		
LEVEL OF HEALTH AND SAFETY PROTECTION	**Level 3** These control measures do not control the hazard at the source. They rely on human behaviour and supervision, and used on their own tend to be the least effective in minimising risks.	**Administrative**	• Documenting a standard operating procedure (SOP) and include in the induction program for all staff required to perform the activity • Developing a proficiency based training program if required by the risk assessment (see definitions) (Workers may be trained against the SOP Appendix E or other assessment criteria.) • Training workers to use control measures implemented when carrying out the activity • Introducing a second operator • Providing signage or warning labels • Restricting access • Maintenance and testing programs • Changing the work organisation e.g. relocating equipment or items, rotating workers between different activities	**RELIABILITY OF CONTROL MEASURES**
LOWEST	Exposure is only limited if the worker wears and uses the PPE correctly.	**Personal Protective Equipment (PPE)**	Requiring the use of one or more of the following: • ear protection (ear muffs) • respirators • face masks • hard hats/helmet • gloves, aprons • eye protection (glasses, shield, visor) • non-slip footwear • appropriate clothing	LEAST

For further examples and explanation on the Hazard Management and Risk Control process, please refer to the Code of Practice for How to manage WHS Risks (2011).

HAZARD MANAGEMENT – RISK ASSESSMENT(LONG FORM)

Stage 1:	Hazard Identification	Residual risk rating L, M, H, VH	M
Name or description of the activity(s) to be assessed	WA Line marking and lane support systems (2018): Driving and steering to activate lane departure warning alarm	Date:	13/02/2018
Area, School/Branch Building/Room	CASR/ECMS		
Workers completing the risk assessment. Name and contact details	MUNISH KUMAR	Mobile/Phone	0433 381 701
	ANDREW VAN DEN BERG	Mobile/Phone	08 8363 0555
	JAMIE MACK MACKENZIE	Mobile/Phone	08 8313 7329

- This template or equivalent template can be used. Please note that this list is not exhaustive, but can be used as the basis for your initial hazard identification.
- If you tick yes to any of the hazards listed below, then the hazard is to be transferred and addressed on **Appendix C2.**
  Where a number of activities have the same hazards, they may be grouped together on the same assessment and the same control measures applied to each.

Consider – is there potential for, or identified exposure to any of the following, as part of a process/activity

	Physical/Environmental Hazards		**Plant and Equipment hazards**
☐	Animals (e.g. hazardous wild animals, bees, snakes)	☐	Mobile lifting equipment or farm machinery
☐	Confined space entry (e.g. pit, tank, silo, entry through a hatch)	☐	Pressurised vessels/systems (e.g. autoclave, boiler)
☐	Fall from a height (e.g. ladder, elevated platform, cliff, scaffolding)	☐	Hazardous levels of heat or vibration (to whole or part body)
☐	Fire (potential for uncontrolled fire due to ignition sources)	☐	Hazardous plant (e.g. lathes, lasers, microtomes, cryostats,
☒	Flying or moving items/plant/vehicles, falling object(s)		or operations could result in amputation, eye injury, serious
☐	Hazardous terrain or environment including wet/slippery surfaces		laceration, crushing injury)
☐	Lighting/visibility is compromised and hazardous		**Radiation hazards**
☐	Noise or sound levels > 85dB(A) or peak level of greater than	☐	Sealed sources or unsealed sources
	135 dB(C) for any period of time	☐	Artificial sources (UV)
☐	Temperature or weather extremes (e.g. hypothermia, major burns)		**Biological hazards (e.g. via inhalation, contact, digestion)**
☐	Isolation (e.g. work in a remote area, difficult to access work site,	☐	Contamination (e.g. pathogens, body fluids)
	or a rescue effort would be difficult in the event of an emergency.	☐	Animal handling (e.g. bites, allergies)
☐	Boating and/or Diving (e.g. risk of drowning)	☐	Other
	Communications		**Chemical hazards**
☐	Communication problems (e.g. by virtue of location or isolation)	☐	Explosive substances
	Electrical	☐	Flammable substances, gas, airborne contaminants
☐	Electric shock	☐	Toxic or asphyxiate gas (e.g. CO_2 including dry ice, liquid N_2)
	Ergonomic/Hazardous Manual activity/task(s)	☐	Respiratory irritants (e.g. nanotech, dust, asbestos)
☐	Work requiring repetitive force or movement	☐	Chemical spraying (e.g. agricultural, pesticides)
☐	Sustained force/posture or awkward posture	☐	Prohibited and restricted carcinogens requiring a permit
☐	Working with animals, unpredictable/unbalanced loads	☐	Hazardous chemicals (not included above)
☐	Transfer of item(s) up or down stairs, using both hands or	☐	Other
	requiring the use of lifting equipment from one level to another		**Activity combines a number of different hazards, and**
	Stress/Duress hazards		**the impact/results of interaction is unknown e.g. mixing**
☐	Personal threat e.g. aggressive behaviour, abuse, threat, assault		**chemicals or recognised as a risk e.g. water and electricity.**
	(includes home visits)	☐	Specify -
☐	Fatigue e.g. from excessive work related mental/physical exertion		**High Risk Travel**
	Remote work location or working in isolation	☐	Destination is rated DFAT 3 or 4 (High/Very High)
☐	Medical emergency, difficult to administer/obtain first aid		**High risk work licence required in accordance with WHS Regs**
	gain assistance e.g. access to medical facilities	☐	Boom-type elevating work platform, scaffolding, dogging,
	Other		crane and hoist operation, reach stackers, forklift operation,
☐			pressure equipment operation.
☐			
☐		☐	**No hazards identified. No risk assessment required.**

HAZARD MANAGEMENT

Stage 2 and Stage 3 – Risk Assessment and Control

Record the potential hazards/issues identified in Hazard Identification Process on Appendix C1 **and** **When and where the hazard is present (i.e. when is the worker exposed?)**	**Inherent risk assessment rating** Before controls are implemented (Refer to the risk assessment Tables – Appendix C3) **L, M, H, VH**	**List the control measures implemented (i.e. in place)** • Control measures are to be in accordance with the Hierarchy of Control. Refer to Appendix C3 for examples. • Choose the control(s) that most effectively eliminate the hazard or minimises the risk. • Record the control measures in place under the relevant control measure (e.g. list in order under the following headings - substitution, isolation, engineering, administrative, Personal Protective Equipment). • Ensure that control measures do not introduce new hazards.	**Residual risk rating** After controls in place The highest rating is to be transferred to the top of page C1.
Traffic accident caused when activating lane departure warning alarm	**VH**	Admin – The speed limit will be observed at all times. Admin – The driver will drift towards the edge line slowly without any jerking of the steering wheel. Admin – The driver will be solely responsible for drifting towards the edge line. When the driver believes the wheel has come into contact with the line they will steer back calmly into the lane (whether or not the LDW system has activated).	**Medium**
Traffic accident caused by distraction of other drivers	**VH**	Admin – Prior to the start of data collection, the passenger will check for traffic ahead and behind the vehicle. If there are other vehicles in the general vicinity the data collection for that run will be aborted (the vehicle will travel to the turnaround point to try again).	**Low**
Traffic accident caused during turn around	**VH**	Admin – Turning the vehicle around will only occur in designated areas that have been deemed safe. These areas will be identified during the initial site survey and safety audit. Admin – When turning around the driver will follow the road rules and ensure there is a sufficient gap between other road users.	**Medium**
Driver distracted by operation of equipment	**VH**	Admin – Driver will not operate equipment at any time while the vehicle is in motion. Admin – Passenger will be responsible for operation of equipment.	**Medium**
Driver distracted by equipment mount failing inside vehicle	**H**	Eng. – Cameras will be mounted with high pressure suction cup. Eng. – Camera cables will be routed and secured with adhesive tape. Admin – Cameras will be positioned such that they will not swing or drop into the driver should the suction cup fail.	**Low**
Driver distracted by equipment mount failing outside vehicle	**H**	Eng. – Cameras will be mounted with high pressure suction cup. Eng. – Camera cables will be routed and secured with adhesive tape. Eng. – Camera cables will be routed through the door seals such that the camera will not contact the road should the suction cup fail. Admin – If an external camera suction cup does fail, the driver will continue travelling to a safe location before pulling over.	**Low**
Equipment blocking driver's view of the road	**H**	Admin – Cameras will be located where they do not restrict the driver's field of vision.	**Low**
Equipment blocking driver's view of the instrument panel	**H**	Admin – Cameras will be located where they do not restrict the driver's view of the instrument panel, including the speed indication.	**Low**

HAZARD MANAGEMENT

RISK ASSESSMENT TABLES

Three essential steps are taken:

4. The probability or likelihood of an incident occurring is evaluated;
5. The severity of the potential consequences is calculated or estimated;
6. Based on these two factors, the risks are assigned priority for risk control through the use of a risk rating.

Risk assessment involves examining and evaluating the likelihood/severity/consequence in order to prioritise and implement adequate controls. The risk matrix has been adopted based on the principles of AS/NZS ISO 31000 (2009) Risk Management – Principles and Guidelines and Code of Practice "How to Manage Work Health and Safety Risks (2012).

Likelihood Table

CATEGORY	DESCRIPTION
Almost certain	There is an expectation that an event/incident will occur.
Likely	There is an expectation that an event/incident **could occur** but not certain to occur.
Slight	This expectation lies somewhere in the midpoint between "could" and "improbable".
Unlikely	There is an expectation that an event/incident is doubtful or **improbable** to occur.
Rare	There is no expectation that the event/incident will occur.

Consequences Table

CATEGORY	DESCRIPTION
Severe	Injury resulting in death, permanent incapacity.
Major	Injury requiring extensive medical treatment, hospitalisation, or activities could result in a Notifiable occurrence.
Moderate	Injury requires formal medical treatment (hospital outpatient/doctors visit etc), activities could result in an Improvement Notice.
Minor	Injury requires first aid.
Negligible	Injury requires minor first aid (e.g. bandaid), or result in short term discomfort (e.g. bruise, headache, muscular aches etc), no medical treatment.

Risk matrix

Likelihood	Consequences				
	Negligible	Minor	Moderate	Major	Severe
Almost Certain	Medium	High	Very High	Very High	Very High
Likely	Medium	Medium	High	Very High	Very High
Slight	Low	Medium	High	High	Very High
Unlikely	Low	Low	Medium	Medium	High
Rare	Low	Low	Low	Medium	Medium

<u>If the level of risk is assessed as high or very high</u>

- ❑ Stop the activity; or
- ❑ Tag out the plant/equipment; or
- ❑ Secure any chemical; and
- ❑ Determine if the activity is to:
  - ❑ continue; or
  - ❑ cease

in consultation with your Manager/Supervisor.

Follow the process in 3.5.6.1 where the risk cannot be reduced to medium or low.

HAZARD MANAGEMENT

HIERARCHY OF RISK CONTROL

	Hierarchy of control		Examples of control measures	
HIGHEST	**Level 1**	**Elimination**	• Not introducing the hazard into the workplace. • Designing out the hazards before they are introduced. • Removing the hazard completely. • Not conducting the activity.	MOST
↓	**If this is not practicable then**	↓		↓
	Level 2 Where it is not reasonably practicable to eliminate the hazards and associated risks.	**Substitution**	• Replacing or substituting the hazard with something safer.	
		Isolation	• Isolating the hazard from the people by distance or using barriers.	
		Engineering	• Installing/using a control measure of a physical nature, including a mechanical device or process e.g. trolleys, hoists, guards, residual current devices, fume-hoods, extraction/ventilation systems, RCD protection.	
		↓		
LEVEL OF HEALTH AND SAFETY PROTECTION	**Level 3** These control measures do not control the hazard at the source. They rely on human behaviour and supervision, and used on their own tend to be the least effective in minimising risks.	**Administrative**	• Documenting a standard operating procedure (SOP) and include in the induction program for all staff required to perform the activity • Developing a proficiency based training program if required by the risk assessment (see definitions) (Workers may be trained against the SOP Appendix E or other assessment criteria.) • Training workers to use control measures implemented when carrying out the activity • Introducing a second operator • Providing signage or warning labels • Restricting access • Maintenance and testing programs • Changing the work organisation e.g. relocating equipment or items, rotating workers between different activities	RELIABILITY OF CONTROL MEASURES
↓ LOWEST	Exposure is only limited if the worker wears and uses the PPE correctly.	**Personal Protective Equipment (PPE)**	Requiring the use of one or more of the following: • ear protection (ear muffs) • respirators • face masks • hard hats/helmet • gloves, aprons • eye protection (glasses, shield, visor) • non-slip footwear • appropriate clothing	↓ LEAST

For further examples and explanation on the Hazard Management and Risk Control process, please refer to the Code of Practice for How to manage WHS Risks (2011).

HAZARD MANAGEMENT – RISK ASSESSMENT(LONG FORM)

Stage 1:	**Hazard Identification**	**Residual risk rating L, M, H, VH**	M
Name or description of the activity(s) to be assessed	WA Line marking and lane support systems (2018): Collecting data while driving to/from trial sites	**Date**:	13/02/2018
Area, School/Branch Building/Room	CASR/ECMS		
Workers completing the risk assessment. Name and contact details	MUNISH KUMAR	**Mobile/Phone**	0433 381 701
	ANDREW VAN DEN BERG	**Mobile/Phone**	08 8363 0555
	JAMIE MACKENZIE	**Mobile/Phone**	08 8313 7329

- This template or equivalent template can be used. Please note that this list is not exhaustive, but can be used as the basis for your initial hazard identification.
- If you tick yes to any of the hazards listed below, then the hazard is to be transferred and addressed on **Appendix C2.** Where a number of activities have the same hazards, they may be grouped together on the same assessment and the same control measures applied to each.

Consider – is there potential for, or identified exposure to any of the following, as part of a process/activity

Physical/Environmental Hazards		**Plant and Equipment hazards**	
☐	Animals (e.g. hazardous wild animals, bees, snakes)	☐	Mobile lifting equipment or farm machinery
☐	Confined space entry (e.g. pit, tank, silo, entry through a hatch)	☐	Pressurised vessels/systems (e.g. autoclave, boiler)
☐	Fall from a height (e.g. ladder, elevated platform, cliff, scaffolding)	☐	Hazardous levels of heat or vibration (to whole or part body)
☐	Fire (potential for uncontrolled fire due to ignition sources)	☐	Hazardous plant (e.g. lathes, lasers, microtomes, cryostats,
☒	Flying or moving items/plant/vehicles, falling object(s)		or operations could result in amputation, eye injury, serious
☐	Hazardous terrain or environment including wet/slippery surfaces		laceration, crushing injury)
☐	Lighting/visibility is compromised and hazardous	**Radiation hazards**	
☐	Noise or sound levels > 85dB(A) or peak level of greater than	☐	Sealed sources or unsealed sources
	135 dB(C) for any period of time	☐	Artificial sources (UV)
☐	Temperature or weather extremes (e.g. hypothermia, major burns)	**Biological hazards (e.g. via inhalation, contact, digestion)**	
☐	Isolation (e.g. work in a remote area, difficult to access work site,	☐	Contamination (e.g. pathogens, body fluids)
	or a rescue effort would be difficult in the event of an emergency.	☐	Animal handling (e.g. bites, allergies)
☐	Boating and/or Diving (e.g. risk of drowning)	☐	Other
Communications		**Chemical hazards**	
☐	Communication problems (e.g. by virtue of location or isolation)	☐	Explosive substances
Electrical		☐	Flammable substances, gas, airborne contaminants
☐	Electric shock	☐	Toxic or asphyxiate gas (e.g. CO_2 including dry ice, liquid N_2)
Ergonomic/Hazardous Manual activity/task(s)		☐	Respiratory irritants (e.g. nanotech, dust, asbestos)
☐	Work requiring repetitive force or movement	☐	Chemical spraying (e.g. agricultural, pesticides)
☐	Sustained force/posture or awkward posture	☐	Prohibited and restricted carcinogens requiring a permit
☐	Working with animals, unpredictable/unbalanced loads	☐	Hazardous chemicals (not included above)
☐	Transfer of item(s) up or down stairs, using both hands or	☐	Other
	requiring the use of lifting equipment from one level to another	**Activity combines a number of different hazards, and**	
Stress/Duress hazards		**the impact/results of interaction is unknown e.g. mixing**	
☐	Personal threat e.g. aggressive behaviour, abuse, threat, assault	**chemicals or recognised as a risk e.g. water and electricity.**	
	(includes home visits)	☐	Specify -
☐	Fatigue e.g. from excessive work related mental/physical exertion	**High Risk Travel**	
Remote work location or working in isolation		☐	Destination is rated DFAT 3 or 4 (High/Very High)
☐	Medical emergency, difficult to administer/obtain first aid	**High risk work licence required in accordance with WHS Regs**	
	gain assistance e.g. access to medical facilities	☐	Boom-type elevating work platform, scaffolding, dogging,
Other			crane and hoist operation, reach stackers, forklift operation,
☐			pressure equipment operation.
☐			
☐		☐	**No hazards identified. No risk assessment required.**

HAZARD MANAGEMENT

Stage 2 and Stage 3 – Risk Assessment and Control

Record the potential hazards/issues identified in Hazard Identification Process on Appendix C1 **and** **When and where the hazard is present (i.e. when is the worker exposed?)**	**Inherent risk assessment rating** Before controls are implemented (Refer to the risk assessment Tables – Appendix C3) **L, M, H, VH**	**List the control measures implemented (i.e. in place)** • Control measures are to be in accordance with the Hierarchy of Control. Refer to Appendix C3 for examples. • Choose the control(s) that most effectively eliminate the hazard or minimises the risk. • Record the control measures in place under the relevant control measure (e.g. list in order under the following headings - substitution, isolation, engineering, administrative, Personal Protective Equipment). • Ensure that control measures do not introduce new hazards.	**Residual risk rating** After controls in place The highest rating is to be transferred to the top of page C1.
Traffic accident due to driving fatigue	**VH**	Admin – Two CASR staff will share the driving task. Admin – The driving task will be performed for no more than 2 hours (absolute limit) before resting for 15 minutes. Admin – Rest breaks to be taken when either person feels fatigued. Admin – An excess amount of travel time has been allocated in the itinerary of activities such that there should be no time pressures when travelling.	**Medium**
Driver distracted by operation of equipment	**VH**	Admin – Driver will not operate equipment at any time while the vehicle is in motion. Admin – Passenger will be responsible for operation of equipment.	**Medium**
Driver distracted by equipment mount failing inside vehicle	**H**	Eng. – Cameras will be mounted with high pressure suction cup. Eng. – Camera cables will be routed and secured with adhesive tape. Admin – Cameras will be positioned such that they will not swing or drop into the driver should the suction cup fail.	**Low**
Equipment blocking driver's view of the road	**H**	Admin – Cameras will be located where they do not restrict the driver's field of vision.	**Low**
Equipment blocking driver's view of the instrument panel	**H**	Admin – Cameras will be located where they do not restrict the driver's view of the instrument panel, including the speed indication.	**Low**

HAZARD MANAGEMENT

RISK ASSESSMENT TABLES

Three essential steps are taken:

7. The probability or likelihood of an incident occurring is evaluated;
8. The severity of the potential consequences is calculated or estimated;
9. Based on these two factors, the risks are assigned priority for risk control through the use of a risk rating.

Risk assessment involves examining and evaluating the likelihood/severity/consequence in order to prioritise and implement adequate controls. The risk matrix has been adopted based on the principles of AS/NZS ISO 31000 (2009) Risk Management – Principles and Guidelines and Code of Practice "How to Manage Work Health and Safety Risks (2012).

Likelihood Table

CATEGORY	DESCRIPTION
Almost certain	There is an expectation that an event/incident will occur.
Likely	There is an expectation that an event/incident **could occur** but not certain to occur.
Slight	This expectation lies somewhere in the midpoint between "could" and "improbable".
Unlikely	There is an expectation that an event/incident is doubtful or **improbable** to occur.
Rare	There is no expectation that the event/incident will occur.

Consequences Table

CATEGORY	DESCRIPTION
Severe	Injury resulting in death, permanent incapacity.
Major	Injury requiring extensive medical treatment, hospitalisation, or activities could result in a Notifiable occurrence.
Moderate	Injury requires formal medical treatment (hospital outpatient/doctors visit etc), activities could result in an Improvement Notice.
Minor	Injury requires first aid.
Negligible	Injury requires minor first aid (e.g. bandaid), or result in short term discomfort (e.g. bruise, headache, muscular aches etc), no medical treatment.

Risk matrix

Likelihood	Consequences				
	Negligible	Minor	Moderate	Major	Severe
Almost Certain	Medium	High	Very High	Very High	Very High
Likely	Medium	Medium	High	Very High	Very High
Slight	Low	Medium	High	High	Very High
Unlikely	Low	Low	Medium	Medium	High
Rare	Low	Low	Low	Medium	Medium

<u>If the level of risk is assessed as high or very high</u>

- ❑ Stop the activity; or
- ❑ Tag out the plant/equipment; or
- ❑ Secure any chemical; and
- ❑ Determine if the activity is to:
  - ❑ continue; or
  - ❑ cease

in consultation with your Manager/Supervisor.

Follow the process in 3.5.6.1 where the risk cannot be reduced to medium or low.

HAZARD MANAGEMENT

HIERARCHY OF RISK CONTROL

Level of health and safety protection	Hierarchy of control		Examples of control measures	Reliability of control measures
HIGHEST	**Level 1**	**Elimination**	• Not introducing the hazard into the workplace. • Designing out the hazards before they are introduced. • Removing the hazard completely. • Not conducting the activity.	MOST
	If this is not practicable then	↓		
	Level 2 Where it is not reasonably practicable to eliminate the hazards and associated risks.	**Substitution**	• Replacing or substituting the hazard with something safer.	
		Isolation	• Isolating the hazard from the people by distance or using barriers.	
		Engineering	• Installing/using a control measure of a physical nature, including a mechanical device or process e.g. trolleys, hoists, guards, residual current devices, fume-hoods, extraction/ventilation systems, RCD protection.	
		↓		
LEVEL OF HEALTH AND SAFETY PROTECTION	**Level 3** These control measures do not control the hazard at the source. They rely on human behaviour and supervision, and used on their own tend to be the least effective in minimising risks.	**Administrative**	• Documenting a standard operating procedure (SOP) and include in the induction program for all staff required to perform the activity • Developing a proficiency based training program if required by the risk assessment (see definitions) (Workers may be trained against the SOP Appendix E or other assessment criteria.) • Training workers to use control measures implemented when carrying out the activity • Introducing a second operator • Providing signage or warning labels • Restricting access • Maintenance and testing programs • Changing the work organisation e.g. relocating equipment or items, rotating workers between different activities	**RELIABILITY OF CONTROL MEASURES**
LOWEST	Exposure is only limited if the worker wears and uses the PPE correctly.	**Personal Protective Equipment (PPE)**	Requiring the use of one or more of the following: • ear protection (ear muffs) • respirators • face masks • hard hats/helmet • gloves, aprons • eye protection (glasses, shield, visor) • non-slip footwear • appropriate clothing	LEAST

For further examples and explanation on the Hazard Management and Risk Control process, please refer to the Code of Practice for How to manage WHS Risks (2011).

APPENDIX B

The tables below show the recorded details from all crossing events that were performed during this study. The recorded details are split into three tables; marked centrelines, marked edge lines, and unmarked edge of road.

Table B.1 Warning events on marked centrelines

Date	Time	Temp	Site	Direction	Line type	Vehicle	Speed	Retro-reflectivity	Luminosity	Sun glare	Water on Road	Warning activated
21/2	11:40:50	25	P2	N	Barrier-Broken	A	106.6	234	80,000	No	No	Yes
21/2	11:41:39	25	P2	N	Barrier-Broken	A	103.7	234	80,000	No	No	Yes
21/2	11:47:24	25	P2	N	Barrier-Broken	A	105.2	234	80,000	No	No	Yes
21/2	11:48:13	25	P2	N	Barrier-Broken	A	104.1	234	80,000	No	No	Yes
21/2	16:00:35	34	P2	N	Barrier-Broken	B	107.2	234	80,000	No	No	Yes
21/2	16:01:21	34	P2	N	Barrier-Broken	B	105.0	234	80,000	No	No	Yes
21/2	16:01:43	34	P2	N	Barrier-Broken	B	107.0	234	80,000	No	No	Yes
21/2	16:08:31	31	P2	N	Barrier-Broken	B	104.6	234	80,000	No	No	Yes
21/2	16:08:36	31	P2	N	Barrier-Broken	B	104.5	234	80,000	No	No	Yes
21/2	16:08:52	31	P2	N	Barrier-Broken	B	107.1	234	80,000	No	No	Yes
20/2	16:06:06	26	A1	N	Broken centreline	A	114.5		70,000	No	No	No
20/2	16:06:34	26	A1	N	Broken centreline	A	101.5		70,000	No	No	No
20/2	16:07:32	26	A1	S	Broken centreline	A	107.7		70,000	No	No	Yes
20/2	16:07:39	26	A1	S	Broken centreline	A	108.1		70,000	No	No	Yes
20/2	17:25:17	26	P4	S	Broken centreline	A	102.8	137	35,000	No	No	Yes
20/2	17:25:25	26	P4	S	Broken centreline	A	103.1	137	35,000	No	No	No
20/2	17:29:23	26	P4	N	Broken centreline	A	105.1	57	6,500	No	No	No
20/2	17:29:38	26	P4	N	Broken centreline	A	103.6	57	6,500	No	No	No
20/2	17:29:47	26	P4	N	Broken centreline	A	103.5	57	6,500	No	No	Yes
20/2	17:48:51	26	A3	W	Broken centreline	A	97.4		26,000	Yes	No	Yes
20/2	17:49:53	26	A3	W	Broken centreline	A	103.4		26,000	Yes	No	Yes
20/2	17:50:00	26	A3	W	Broken centreline	A	103.8		26,000	Yes	No	Yes
21/2	09:29:21	21	P4	N	Broken centreline	A	106.7	57	99,000	No	Yes	Yes
21/2	09:29:27	21	P4	N	Broken centreline	A	107.0	57	99,000	No	Yes	Yes
21/2	09:31:29	21	P4	S	Broken centreline	A	107.7	137	99,000	No	Yes	Yes
21/2	09:31:37	21	P4	S	Broken centreline	A	106.3	137	99,000	No	Yes	Yes
21/2	11:18:04	24	P4	N	Broken centreline	A	105.2	57	100,000	No	No	Yes
21/2	11:18:11	24	P4	N	Broken centreline	A	104.5	57	100,000	No	No	Yes

Date	Time	Temp	Site	Direction	Line type	Vehicle	Speed	Retro-reflectivity	Luminosity	Sun glare	Water on Road	Warning activated
21/2	11:18:19	24	P4	N	Broken centreline	A	105.3	57	100,000	No	No	Yes
21/2	11:18:28	24	P4	N	Broken centreline	A	103.8	57	100,000	No	No	Yes
21/2	11:25:48	24	P3	N	Broken centreline	A	105.8	210	100,000	No	No	Yes
21/2	11:25:56	24	P3	N	Broken centreline	A	106.8	210	100,000	No	No	Yes
21/2	11:26:06	24	P3	N	Broken centreline	A	105.8	210	100,000	No	No	Yes
21/2	11:26:13	24	P3	N	Broken centreline	A	106.1	210	100,000	No	No	Yes
21/2	11:26:22	24	P3	N	Broken centreline	A	105.7	210	100,000	No	No	Yes
21/2	13:36:08	31	P4	N	Broken centreline	B	107.2	57	73,000	No	No	Yes
21/2	16:15:59	32	P3	S	Broken centreline	B	105.9	101	15,000	No	No	Yes
21/2	16:16:06	32	P3	S	Broken centreline	B	106.3	101	15,000	No	No	Yes
21/2	16:16:13	32	P3	S	Broken centreline	B	107.4	101	15,000	No	No	Yes
21/2	16:16:26	32	P3	S	Broken centreline	B	107.3	101	15,000	No	No	Yes
21/2	16:32:31	31	P4	S	Broken centreline	B	106.7	137	73,000	No	No	Yes
21/2	16:32:39	31	P4	S	Broken centreline	B	106.8	137	73,000	No	No	Yes
21/2	16:32:47	31	P4	S	Broken centreline	B	105.9	137	73,000	No	No	Yes
21/2	16:32:55	31	P4	S	Broken centreline	B	106.6	137	73,000	No	No	Yes
21/2	16:35:56	31	P4	N	Broken centreline	B	106.2	57	73,000	No	No	Yes
21/2	16:36:03	31	P4	N	Broken centreline	B	107.7	57	73,000	No	No	Yes
21/2	16:36:11	31	P4	N	Broken centreline	B	107.4	57	73,000	No	No	Yes
21/2	16:36:28	31	P4	N	Broken centreline	B	105.6	57	73,000	No	No	Yes
21/2	16:37:06	31	P4	N	Broken centreline	B	88.4	57	73,000	No	No	Yes
21/2	16:37:11	31	P4	N	Broken centreline	B	85.2	57	73,000	No	No	Yes
21/2	17:12:55	29	A1	S	Broken centreline	B	107.1		40,000	No	No	Yes
21/2	17:13:03	29	A1	S	Broken centreline	B	107.4		40,000	No	No	Yes
21/2	17:13:16	29	A1	S	Broken centreline	B	106.5		40,000	No	No	Yes
21/2	17:13:45	29	A1	S	Broken centreline	B	107.4		40,000	No	No	Yes
21/2	17:13:52	29	A1	S	Broken centreline	B	105.8		40,000	No	No	Yes
21/2	17:15:31	29	A1	N	Broken centreline	B	107.6		40,000	No	No	Yes

Date	Time	Temp	Site	Direction	Line type	Vehicle	Speed	Retro-reflectivity	Luminosity	Sun glare	Water on Road	Warning activated
21/2	17:15:40	29	A1	N	Broken centreline	B	106.2		40,000	No	No	Yes
21/2	17:15:49	29	A1	N	Broken centreline	B	105.3		40,000	No	No	Yes
21/2	17:15:59	29	A1	N	Broken centreline	B	107.2		40,000	No	No	Yes
21/2	17:16:07	29	A1	N	Broken centreline	B	107.3		40,000	No	No	Yes
21/2	17:16:15	29	A1	N	Broken centreline	B	107.0		40,000	No	No	Yes
21/2	17:16:21	29	A1	N	Broken centreline	B	107.6		40,000	No	No	Yes
21/2	17:16:32	29	A1	N	Broken centreline	B	105.7		40,000	No	No	Yes
21/2	18:04:49	29	A3	W	Broken centreline	B	81.2		11,000	Yes	No	Yes
21/2	18:05:49	29	A3	W	Broken centreline	B	77.7		11,000	Yes	No	Yes
21/2	18:06:05	29	A3	W	Broken centreline	B	88.1		11,000	Yes	No	Yes
21/2	18:06:36	29	A3	W	Broken centreline	B	84.2		11,000	Yes	No	Yes
21/2	18:06:55	29	A3	W	Broken centreline	B	84.6		11,000	Yes	No	Yes
22/2	08:51:39	24	P4	N	Broken centreline	B	105.3	57	60,000	No	Yes	Yes
22/2	08:51:46	24	P4	N	Broken centreline	B	101.0	57	60,000	No	Yes	Yes
22/2	08:51:52	24	P4	N	Broken centreline	B	98.6	57	60,000	No	Yes	Yes
22/2	08:54:05	24	P4	S	Broken centreline	B	106.4	137	60,000	No	Yes	Yes
22/2	08:54:12	24	P4	S	Broken centreline	B	105.0	137	60,000	No	Yes	Yes
22/2	08:54:18	24	P4	S	Broken centreline	B	106.1	137	60,000	No	Yes	Yes
20/2	17:49:35	26	A3	W	Broken-Barrier	A	102.0		26,000	Yes	No	Yes
21/2	11:43:32	25	P2	S	Broken-Barrier	A	107.1	119	80,000	No	No	Yes
21/2	11:43:37	25	P2	S	Broken-Barrier	A	107.1	119	80,000	No	No	Yes
21/2	11:49:54	25	P2	S	Broken-Barrier	A	107.3	119	80,000	No	No	Yes
21/2	11:50:44	25	P2	S	Broken-Barrier	A	104.4	119	80,000	No	No	Yes
21/2	16:03:51	34	P2	S	Broken-Barrier	B	108.0	119	80,000	No	No	Yes
21/2	16:03:56	34	P2	S	Broken-Barrier	B	108.4	119	80,000	No	No	Yes
21/2	16:04:40	34	P2	S	Broken-Barrier	B	105.6	119	80,000	No	No	Yes
21/2	16:10:50	32	P2	S	Broken-Barrier	B	105.6	119	80,000	No	No	Yes
21/2	16:11:08	32	P2	S	Broken-Barrier	B	107.8	119	80,000	No	No	Yes

Date	Time	Temp	Site	Direction	Line type	Vehicle	Speed	Retro-reflectivity	Luminosity	Sun glare	Water on Road	Warning activated
21/2	16:11:57	32	P2	S	Broken-Barrier	B	105.7	119	80,000	No	No	Yes
21/2	18:04:24	29	A3	W	Broken-Barrier	B	72.6		11,000	Yes	No	Yes
21/2	18:04:35	29	A3	W	Broken-Barrier	B	76.5		11,000	Yes	No	Yes
21/2	18:05:41	29	A3	W	Broken-Barrier	B	80.3		11,000	Yes	No	Yes
21/2	08:48:10	20	P1	S	Double Barrier	A	106.8	105	78,000	No	No	Yes
21/2	08:48:14	20	P1	S	Double Barrier	A	106.7	105	78,000	No	No	Yes
21/2	08:51:11	20	P1	N	Double Barrier	A	107.4	201	78,000	No	No	Yes
21/2	08:51:17	20	P1	N	Double Barrier	A	108.8	201	78,000	No	No	Yes
21/2	08:54:12	20	P1	S	Double Barrier	A	108.7	105	74,800	No	No	Yes
21/2	08:54:18	20	P1	S	Double Barrier	A	108.7	105	74,800	No	No	Yes
21/2	15:45:10	30	P1	S	Double Barrier	B	102.0	105	77,000	No	No	Yes
21/2	15:45:13	30	P1	S	Double Barrier	B	105.2	105	77,000	No	No	Yes
21/2	15:47:28	30	P1	N	Double Barrier	B	106.9	201	77,000	No	No	Yes
21/2	15:50:07	30	P1	S	Double Barrier	B	90.9	105	77,000	No	No	Yes
21/2	15:50:13	30	P1	S	Double Barrier	B	87.9	105	77,000	No	No	Yes

Table B.2 Warning events on marked edge lines

Date	Time	Temp	Site	Direction	Line type	Vehicle	Speed	Retro-reflectivity	Luminosity	Sun glare	Water on road	Warning activated
21/2	12:13:53	26	A3	W	Solid Edge Line	A	55.2		130,000	No	No	No
21/2	18:15:43	29	A3	E	Solid Edge Line	B	47.6		4,600	No	No	Yes
21/2	18:15:49	29	A3	E	Solid Edge Line	B	48.2		4,600	No	No	Yes
21/2	18:15:56	29	A3	E	Solid Edge Line	B	36.3		4,600	No	No	No
21/2	18:16:03	29	A3	E	Solid Edge Line	B	40.3		4,600	No	No	No
21/2	18:16:06	29	A3	E	Solid Edge Line	B	44.2		4,600	No	No	Yes
22/2	09:41:09	26	A3	E	Solid Edge Line	B	47.3		91,000	No	No	Yes
22/2	09:41:17	26	A3	E	Solid Edge Line	B	47.7		91,000	No	No	Yes
22/2	09:41:24	26	A3	E	Solid Edge Line	B	44.4		91,000	No	No	No
20/2	16:24:24	26	P5	N	ATEL+DS	A	86.1	119	70,000	No	No	Yes
20/2	16:24:32	26	P5	N	ATEL+DS	A	86.3	119	70,000	No	No	Yes
20/2	16:27:19	26	P5	S	ATEL+DS	A	89.8	156	70,000	No	No	Yes
20/2	16:27:29	26	P5	S	ATEL+DS	A	89.4	156	70,000	No	No	Yes
20/2	16:29:44	26	P5	N	ATEL+DS	A	93.2	119	70,000	No	No	Yes
20/2	16:29:51	26	P5	N	ATEL+DS	A	91.5	119	70,000	No	No	Yes
21/2	16:55:41	29	P5	S	ATEL+DS	B	106.5	156	50,000	No	No	Yes
21/2	16:55:52	29	P5	S	ATEL+DS	B	85.7	156	50,000	No	No	Yes
21/2	16:55:58	29	P5	S	ATEL+DS	B	86.2	156	50,000	No	No	No
21/2	16:57:24	29	P5	N	ATEL+DS	B	87.1	119	50,000	No	No	Yes
21/2	16:57:32	29	P5	N	ATEL+DS	B	86.6	119	50,000	No	No	Yes
21/2	16:57:39	29	P5	N	ATEL+DS	B	86.7	119	50,000	No	No	Yes
21/2	16:57:56	29	P5	N	ATEL+DS	B	87.0	119	50,000	No	No	Yes
21/2	17:00:17	29	P5	S	ATEL+DS	B	86.3	156	50,000	No	No	Yes
21/2	17:00:24	29	P5	S	ATEL+DS	B	87.0	156	50,000	No	No	Yes
21/2	17:00:31	29	P5	S	ATEL+DS	B	86.7	156	50,000	No	No	Yes
21/2	17:00:40	29	P5	S	ATEL+DS	B	85.9	156	50,000	No	No	Yes
21/2	11:29:28	24	P3	S	ATEL	A	106.0	123	100,000	No	No	Yes
21/2	11:29:36	24	P3	S	ATEL	A	106.2	123	100,000	No	No	Yes

Date	Time	Temp	Site	Direction	Line type	Vehicle	Speed	Retro-reflectivity	Luminosity	Sun glare	Water on road	Warning activated
21/2	11:29:45	24	P3	S	ATEL	A	106.4	123	100,000	No	No	Yes
21/2	11:29:53	24	P3	S	ATEL	A	105.8	123	100,000	No	No	Yes
21/2	11:30:00	24	P3	S	ATEL	A	106.1	123	100,000	No	No	Yes
21/2	11:30:11	24	P3	S	ATEL	A	56.8	123	100,000	No	No	Yes
21/2	11:32:29	24	P3	N	ATEL	A	106.5	153	100,000	No	No	Yes
21/2	11:32:36	24	P3	N	ATEL	A	106.1	153	100,000	No	No	Yes
21/2	11:32:43	24	P3	N	ATEL	A	105.2	153	100,000	No	No	Yes
21/2	11:32:52	24	P3	N	ATEL	A	105.3	153	100,000	No	No	Yes
21/2	16:21:47	33	P3	N	ATEL	B	106.7	153	68,000	No	No	Yes
21/2	16:21:54	33	P3	N	ATEL	B	106.4	153	68,000	No	No	Yes
21/2	16:22:02	33	P3	N	ATEL	B	106.2	153	68,000	No	No	Yes
21/2	16:22:10	33	P3	N	ATEL	B	107.1	153	68,000	No	No	Yes
21/2	16:22:19	33	P3	N	ATEL	B	107.5	153	68,000	No	No	Yes
21/2	16:22:29	33	P3	N	ATEL	B	106.8	153	68,000	No	No	Yes
21/2	16:22:38	33	P3	N	ATEL	B	107.7	153	68,000	No	No	Yes
21/2	16:24:48	33	P3	S	ATEL	B	108.2	123	68,000	No	No	Yes
21/2	16:24:57	33	P3	S	ATEL	B	107.4	123	68,000	No	No	Yes
21/2	16:25:06	33	P3	S	ATEL	B	106.5	123	68,000	No	No	Yes
21/2	16:25:15	33	P3	S	ATEL	B	106.3	123	68,000	No	No	Yes
21/2	16:25:22	33	P3	S	ATEL	B	106.6	123	68,000	No	No	Yes
21/2	16:25:31	33	P3	S	ATEL	B	107.2	123	68,000	No	No	Yes

* Line type acronyms

ATEL+DS = Audio-Tactile Edge Line with Dark Shoulder

ATEL = Audio-Tactile Edge Line

Table B.3 Warning events on unmarked road edges

Date	Time	Temp	Site	Direction	Line type*	Vehicle	Speed	Retro-reflectivity	Luminosity	Sun glare	Water on road	Warning activated
21/2	12:13:30	26	A3	W	None	A	53.9		130,000	No	No	No
21/2	12:15:16	26	A3	E	None	A	62.4		130,000	No	No	Yes
21/2	12:15:23	26	A3	E	None	A	61.4		130,000	No	No	Yes
22/2	09:39:07	26	A3	W	None	B	46.3		91,000	No	No	No
22/2	09:39:18	26	A3	W	None	B	46.6		91,000	No	No	No
22/2	09:40:40	26	A3	E	None	B	48.6		91,000	No	No	No
21/2	12:12:03	26	A3	E	None	A	66.8		130,000	No	No	Yes
22/2	09:41:02	26	A3	E	None	B	47.2		91,000	No	No	No
20/2	16:54:34	26	A4	W	None	A	68.3		70,000	No	No	No
20/2	16:55:33	26	A4	E	None	A	65.4		70,000	No	No	No
20/2	16:55:53	26	A4	E	None	A	65.3		70,000	No	No	Yes
21/2	10:18:36	22	A2	E	None	A	62.9		113,000	No	Yes	No
21/2	10:27:30	22	A2	W	None	A	64.5		113,000	No	No	No
21/2	10:27:41	22	A2	W	None	A	64.7		113,000	No	No	Yes
21/2	10:28:00	22	A2	W	None	A	64.9		113,000	No	No	Yes
21/2	10:29:21	22	A2	W	None	A	64.2		113,000	No	No	Yes
21/2	12:13:18	26	A3	W	None	A	53.6		130,000	No	No	No
21/2	12:13:44	26	A3	W	None	A	53.6		130,000	No	No	No
21/2	17:29:09	26	A4	W	None	B	41.7		46,000	No	No	No
21/2	17:29:22	26	A4	W	None	B	42.5		46,000	No	No	No
21/2	17:30:01	26	A4	E	None	B	48.8		46,000	No	No	No
21/2	17:30:28	26	A4	E	None	B	47.6		46,000	No	No	No
21/2	17:30:36	26	A4	E	None	B	47.2		46,000	No	No	No
22/2	09:05:10	25	A2	E	None	B	57.0		72,000	No	No	Yes
22/2	09:05:19	25	A2	E	None	B	57.1		72,000	No	No	No
22/2	09:05:26	25	A2	E	None	B	57.1		72,000	No	No	No
22/2	09:05:51	25	A2	E	None	B	56.4		72,000	No	No	Yes
22/2	09:06:01	25	A2	E	None	B	56.3		72,000	No	No	No

Date	Time	Temp	Site	Direction	Line type*	Vehicle	Speed	Retro-reflectivity	Luminosity	Sun glare	Water on road	Warning activated
22/2	09:07:06	25	A2	W	None	B	59.1		72,000	No	No	Yes
22/2	09:07:13	25	A2	W	None	B	56.9		72,000	No	No	Yes
22/2	09:07:32	25	A2	W	None	B	56.8		72,000	No	No	No
22/2	09:07:44	25	A2	W	None	B	57.1		72,000	No	No	No
22/2	09:07:55	25	A2	W	None	B	56.8		72,000	No	No	No
22/2	09:08:04	25	A2	W	None	B	57.3		72,000	No	No	No
22/2	09:08:15	25	A2	W	None	B	57.6		72,000	No	No	No
22/2	09:38:57	26	A3	W	None	B	47.0		91,000	No	No	No
21/2	12:11:53	26	A3	E	Pseudo SEL	A	66.3		130,000	No	No	Yes
21/2	12:11:57	26	A3	E	Pseudo SEL	A	66.4		130,000	No	No	Yes
21/2	12:15:33	26	A3	E	Pseudo SEL	A	62.0		130,000	No	No	Yes
22/2	09:40:47	26	A3	E	Pseudo SEL	B	47.1		91,000	No	No	Yes
22/2	09:40:53	26	A3	E	Pseudo SEL	B	47.4		91,000	No	No	Yes

* Line type acronyms:

Pseudo SEL = Pseudo Solid Edge Line