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# FINAL REPORT

Project Title: P53: Effects of Wide Centre Line Treatment on Pavements Y1 & Y2 (2015/16 & 2016/17)

ARRB Project No: PRP16038


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Client: Queensland Department of Transport and Main Roads

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AN INITIATIVE BY:

# SUMMARY

In the last two-to-three years, the Queensland Department of Transport and Main Roads (the Department) has trialled and implemented the Wide Centre Line Treatment (WCLT) program to reduce the risk of head-on crashes. WCLT guidelines were developed and the Department issued an interim Technical Note TN155* in November 2015.

The aim of the first part of this study was to establish the status of WCLTs on the Department's road network and identify whether any significant pavement issues have been caused by their implementation. The Department also requested that the study establish heavy vehicle wheel path distributions in varying line-marking conditions for both WCLT and non-WCLT sections (i.e. single-line median).

While discussions with pavement engineering practitioners suggested that longer pavement life could be achieved by relocating the loaded wheel path, there are a number of possible pavement failure mechanisms that could occur in situations where a load path has been relocated. Some District representatives were contacted and followed up by site visits to the Darling Downs and Far North Districts to ascertain if there were any endemic pavement issues being experienced as a result of the treatments.

In summary, the study did not find significant impacts of WCLTs on the short-term performance of pavements.

The second part of the study investigated the wheel paths of heavy vehicles along both WCLT and non-WCLT linemarked road sections. In collaboration with researchers from the Central Queensland University (CQU), a video analysis technique was developed and deployed at six different test sites in the Mackay and Warwick Districts. The imagery data collected from the test sites were used to track the lateral wheel position along different WCLT and non-WCLT sections of road.

The mean distance from the edge line was generally greater in the WCLT sites than the non-WCLT sites. This is an interesting finding because this observation is contrary to the common belief that heavy vehicles will travel closer to the left edge line after the treatment. For Mackay sites, the distance from the edge line on average did not significantly change between WCLT and non-WCLT sites. Lane width and shoulder width appear to have little effect on the average tyre position in relation to the edge line. For the Warwick sites, heavy vehicles tended to travel further away from the edge line than in the non-WCLT sections. The data suggested that, as commonly expected, all WCLT sections have the right edge of the wheel travelling further away from the crown.

The study has also identified a portable, cost-effective and accurate method to track the wheel paths of heavy vehicles when travelling on WCLT and non-WCLT sections of the road network.

Some recommended updates to TN155 are provided, including a requirement to undertake a pavement due diligence investigation before implementing a treatment on a particular section of road. The reason for the differences in behaviour in the Mackay and Warwick sites is unclear. It is suspected that factors such as lane width, shoulder width, the presence of a slip lane, and the position of the camera can influence the results. Future research should expand the number of testsites and testing techniques to ascertain the influence of these factors in a more controlled manner.



**TN155 was withdrawn in December 2019 and incorporated in the Supplement to Austroads Guide to Road Design, the Road Planning and Design Manual, Volume 3 (August 2018).*

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# 1 PROJECT BACKGROUND AND OVERVIEW

In the last two-to-three years, the Queensland Department of Transport and Main Roads (the Department) has trialled and implemented a nominally 1 m wide centre line treatment (WCLT) to reduce the risk of head-on crashes. A typical WCLT layout is shown in Figure 1.1. The photograph was taken along the Bruce Highway on the Townsville – Ingham section (Road 10M Chainage 88.84 km).

**Figure 1.1: Example of a typical wide centre line treatment**

WCLT guidelines were developed and the Department issued an interim Technical Note TN155* in November 2015 (Queensland Department of Transport and Main Roads 2015). TN155 provides guidance on how and where to implement a WCLT, including consideration of key input parameters such as seal width, sealed shoulder width, the maximum length of heavy vehicle type allowed on the road, and traffic volume.

It is worth noting that a number of TMR Districts which were involved in the early trialling of WCLTs have implemented WCLT arrangements that now may not meet the lane width and shoulder seal width requirement in the current interim guidelines.

To implement a WCLT, the edge line is often moved outwards to continue to provide sufficient lane width. Some WCLT sections have experienced accelerated pavement failures, and the hypothesis by some Districts was that the WCLT had contributed to the cause of failure, either by:

(a) causing a concentration, or increased channelisation of heavy vehicle traffic, therefore increasing the actual load experienced by the pavement structure
(b) inducing a lateral shift of the loaded wheel path, exposing a previously untrafficked pavement structure to loading, this could result in:
   - trafficking a thinner and/or weaker pavement structure
   - trafficking lower quality materials located in the shoulder
   - trafficking a different type of surfacing compared to the traffic lanes

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- trafficking the same type of surfacing, but with different sprayed seal binder application rates,

or

(c) a combination of (a) and (b).

The purpose of this study was to establish the status of WCLTs on the Department's road network and identify whether their implementation has caused any significant pavement issues.

The Department also requested that this study investigate the heavy vehicle wheel path distributions experienced in different linemarking conditions for both WCLT and non-WCLT sections (i.e. single-line median). Researchers at Central Queensland University (CQU) were also engaged to investigate the use of an automated image processing technique to monitor the wheel paths of heavy vehicles on a number of WCLT and non-WCLT road sections.

# 2 RESEARCH METHODOLOGY

The project was undertaken in three parts, as follows:

Part 1

- Comments were invited from engineers and engineering managers across the state.
- Field inspections were undertaken in the Districts that are experiencing pavement issues possibly due to the implementation of WCLTs.
- Where site visits were not possible, the Department's Digital Video Road (DVR) data was reviewed to identify any potential pavement issues.

Part 2

- The WCLT information obtained during part 1 was summarised.
- The stakeholder feedback was analysed and summarised.
- Technical review and comparison with the interim guideline in TN155 were undertaken.
- A checklist that will assist engineers in determining the pavement risk as part of the process that identifies whether a site is suitable for WCLT implementation was developed.

Part 3

- Cost-effective technology suitable for accurately recording and presenting heavy vehicle wheel path distribution (i.e. vehicle wander) was investigated.
- A rationale for choosing suitable representative WCLT and non-WCLT sites for further assessment was developed.
- A field assessment to understand the distribution of heavy vehicle wheel paths was undertaken.

# 3 WCLT IN QUEENSLAND

## 3.1 WLCT Design Requirements

The WCLT design requirements are outlined in TN155, as shown in Table 3.1 and Table 3.2. The lane and shoulder configurations will depend on the traffic volume, heavy vehicle type and design standard (i.e. normal design domain or extended design domain).

**Table 3.1: Normal design domain cross-section for a WCLT (two-lane, two-way roads)**

| Design AADT | Vehicle routes | Sealed shoulder width(2) (m) | Lane width(1) (m) | WCLT width (m) | Total seal width (m) |
|---|---|---|---|---|---|
| 2000 – 4000 | All vehicles up to B-double | 1.75 | 3.25 | 1.0 | 11.0 |
| | Type 1 road train | 1.50 | 3.50 | 1.0 | |
| | Type 2 road train | 1.25 | 3.75 | 1.0 | |
| > 4000 | All vehicles up to B-double | 1.75 | 3.25 | 1.0 | 11.0(3) |
| | Type 1 road train | 1.50 | 3.50 | 1.0 | |
| | Type 2 road train | 1.25 | 3.75 | 1.0 | |
| | All vehicles up to B-double | 2.00 | 3.25 | 1.0 | 11.5 |
| | Type 1 road train | 1.75 | 3.50 | 1.0 | |
| | Type 2 road train | 1.5 | 3.75 | 1.0 | |

**Table 3.2: Extended design domain cross-section for a WCLT (two-lane, two-way roads)**

| Design AADT | Vehicle routes | Sealed shoulder width [2] (m) | Lane width [1] (m) | WCLT width (m) | Total seal width |
|---|---|---|---|---|---|
| **2000 – 4000** | All vehicles up to B-double | 1.25 | 3.25 | 1.0 | 10.0 |
| | Type 1 road train | 1.00 | 3.50 | 1.0 | |
| | Type 2 road train | 1.00 | 3.75 | 1.0 | 10.5 |
| **> 4000** | All vehicles up to B-double | 1.25 | 3.25 | 1.0 | 10.0[3] |
| | Type 1 road train | 1.00 | 3.50 | 1.0 | |
| | Type 2 road train | 1.00 | 3.75 | 1.0 | 10.5[3] |
| | All vehicles up to B-double | 1.50 | 3.25 | 1.0 | 10.5 |
| | Type 1 road train | 1.25 | 3.50 | 1.0 | |
| | Type 2 road train | 1.25 | 3.75 | 1.0 | 11.0 |

1 In situations with more than one lane in a single direction, the lane width is the same for all lanes.
2 In situations with an auxiliary lane, a shoulder width of 1.0 m is often satisfactory. This width should be increased in areas of restricted visibility (e.g. around curves) and in the merge area at the end of the lane.
3 These cross-sections should only be used on roads in cuttings, or low embankments or where the batter slope does not exceed 1V:4H (desirably 1V:6H) – i.e. recoverable for cars. If roadside barriers are used, additional verge width should be applied when needed to accommodate the barrier.

## 3.2 Status of WCLTs in Queensland

ARMIS data was extracted from the Department's database on 11 April 2016, and was made available to the research team as 100 m segmented data.

A map of WCLT locations is provided in Figure 3.1. At the time of the analysis, the Department had implemented 370 continuous segments, providing a total of 795 km of WCLTs in seven Districts along 14 different highways. Over 75% of the WCLTs are located along the Bruce Highway.

As shown in Figure 3.2, 50% of the treatments located in two districts, i.e. Mackay/Whitsunday and Fitzroy.

Figure 3.1: Locations of WCLT sites across QLD


The distribution of WCLT sections across the Districts and the associated traffic volumes is also shown in Figure 3.2 and Figure 3.3. The Mackay/Whitsunday District has the longest total length of WCLTs, totalling 231 km. The Fitzroy District also has a considerable length totalling 215 km that has the treatment. WCLTs have mainly been implemented on two-way, two-lane rural highways in 100 km/h environments, with traffic volumes greater than 1000 vehicles per day. One-third of the WCLT sections have traffic volumes more than 5000 vehicles per day.

**Figure 3.2: Distribution of WCLTs by district**

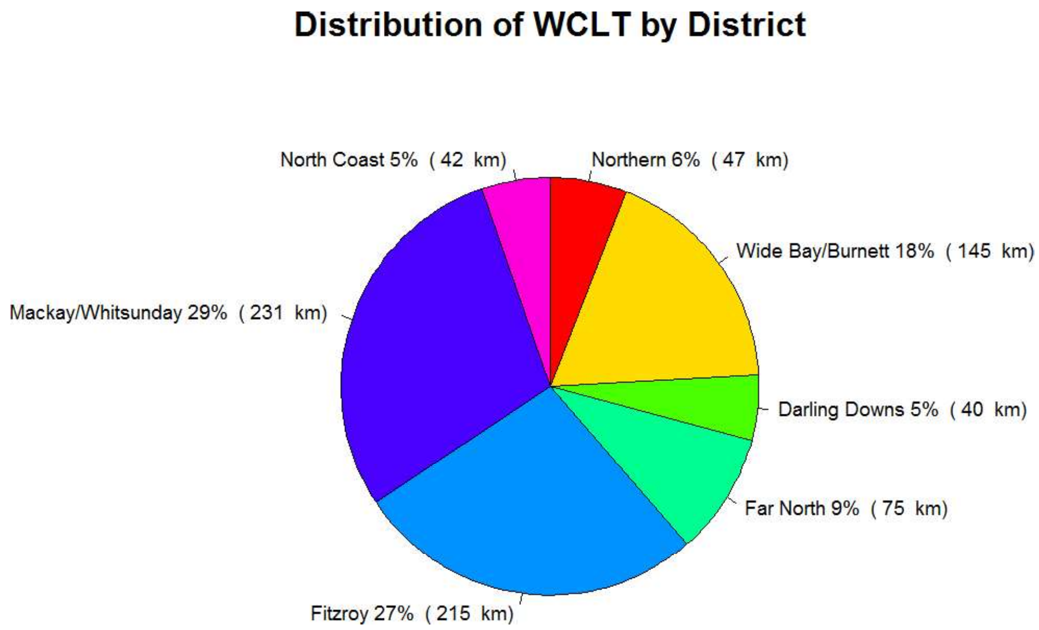
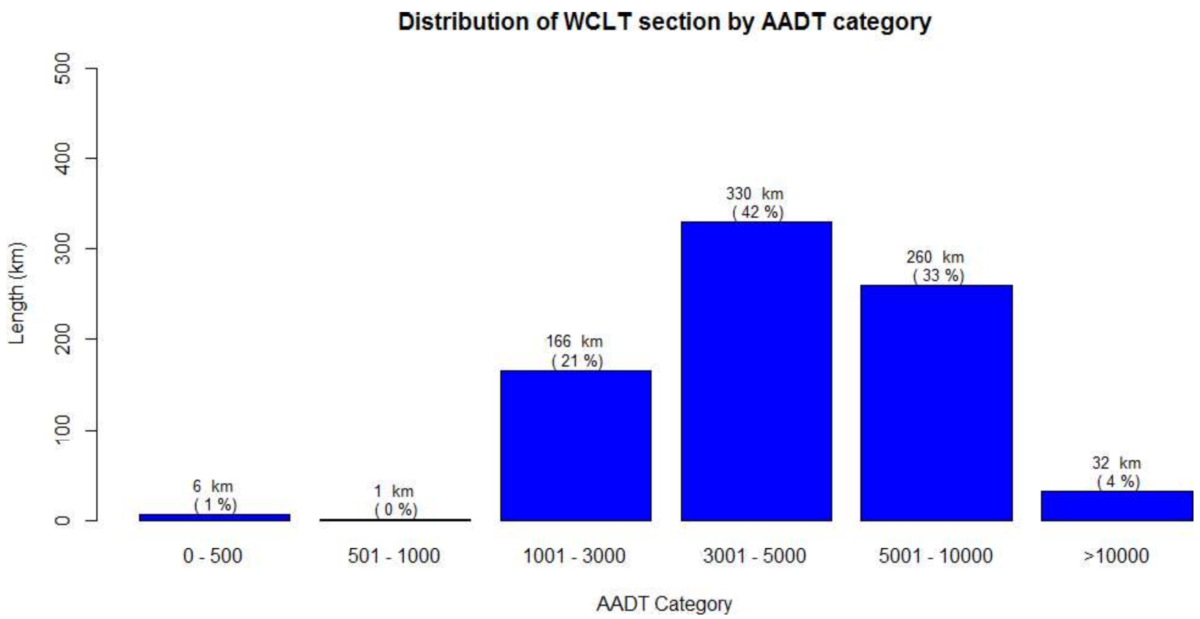


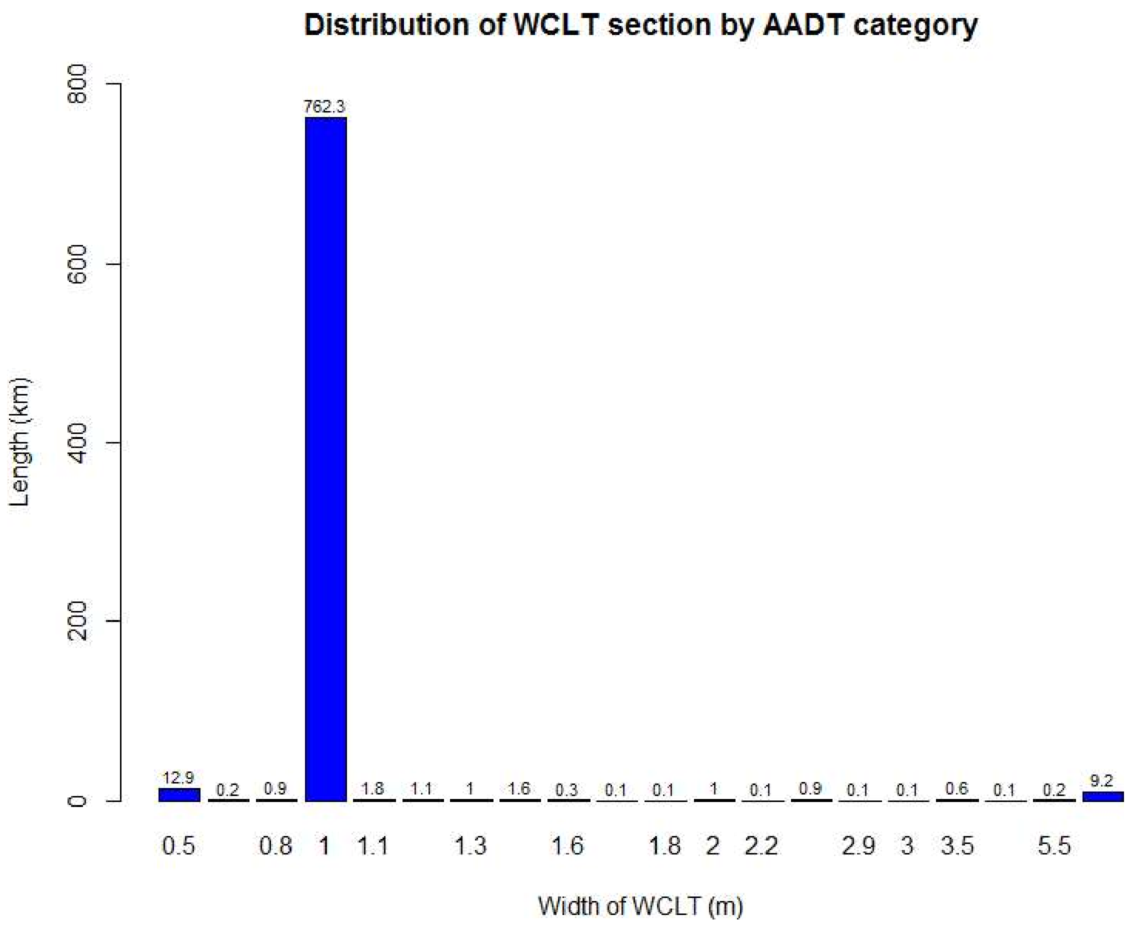

**Figure 3.3: Distribution of WCLTs by average annual daily traffic (AADT)**




### *3.2.1 Width of WCLTs*

Figure 3.4 presents the distribution of WCLT width according to the ARMIS data provided. It shows that 762 km (96%) of WCLTs are consistent with TN155 by providing a 1m width. In the remaining 4%, the widths range from 0.5 m to 3.5 m.

**Figure 3.4: WCLTs width distribution**




### *3.2.2 Width of lanes and sealed shoulder*

A summary of the lane widths and shoulder widths along WCLT sections is provided in Figure 3.5 and Figure 3.6. It shows that the lane widths vary between 2.9 and 4.0 m, with the following distribution:

- 3.0 m (25%)
- 3.3 m (45%) (3.3 m is most likely equal to 3.25 m, as the ARMIS database only records this field to 1 decimal place accuracy)
- 3.5 m (25%).

The shoulder widths vary between 0.5 m and 3.0 m, with the most common widths (78%) listed below:

- 1.0 m (5%)
- 1.2 m (11%)
- 1.5 m (20%)
- 1.7 m (7%)
- 2.0 m (35%).

Figure 3.5: Lane width distribution along WCLT sections

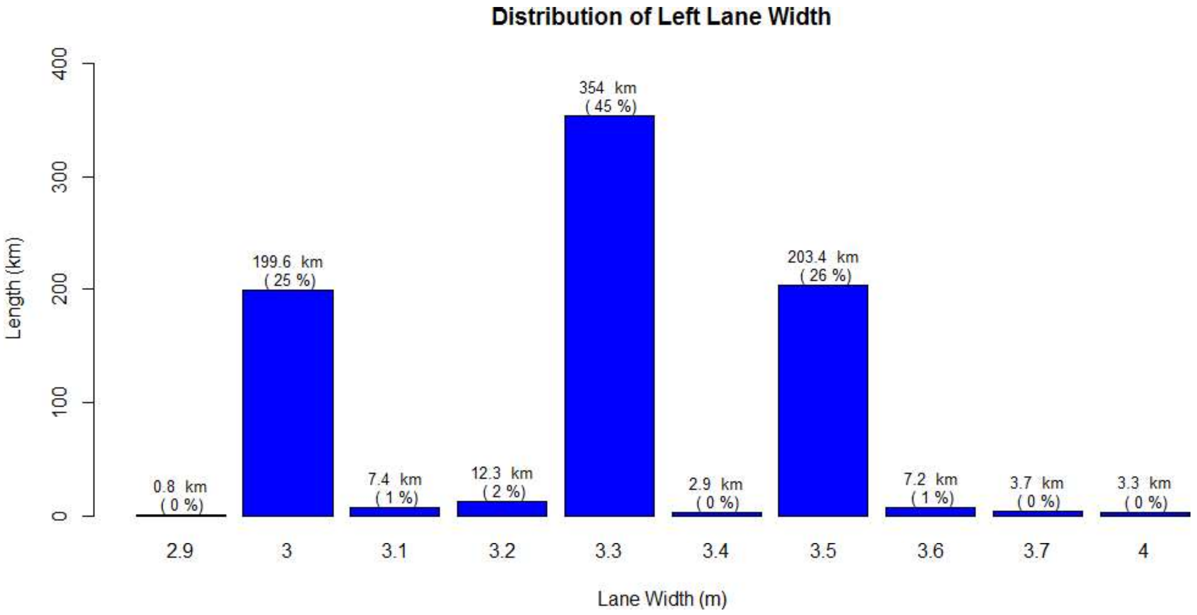



Figure 3.6: Sealed shoulder width distribution along WCLT sections

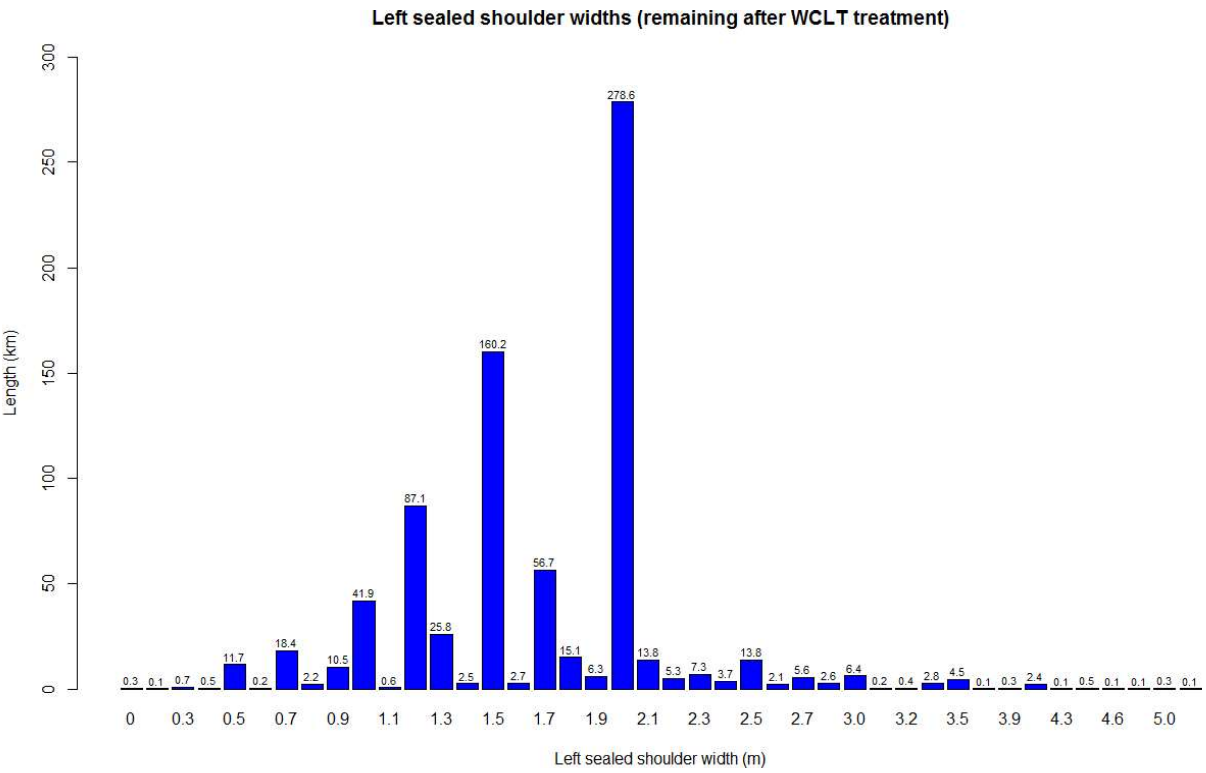
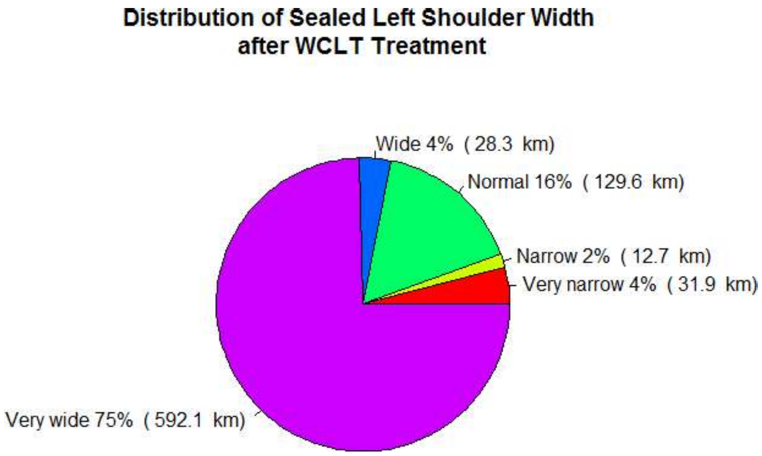



Figure 3.7 shows the distribution of the sealed left (outer) shoulder width along the WCLT sections. The data is summarised by grouping the different sealed widths into descriptive categories (i.e. very narrow, narrow, normal, wide and very wide). The majority of the sealed width exceeds 1.5 m after the implementation of the WCLT.

**Figure 3.7: Distribution of sealed shoulders by category**




| Sealed Width Category | Range of Sealed Width |
|---|---|
| Very narrow | 0 - 0.75m |
| Narrow | 0.75 - 1m |
| Normal | 1 - 1.25m |
| Wide | 1.25 - 1.5m |
| Very wide | 1.5 - 10m |

The ARMIS data did not include any information on the maximum allowable vehicle type on each of the treated sections. It was therefore not possible to assess the lane widths, shoulder widths and WCLT widths against the requirements in TN155. However, most of the routes are major highways with higher traffic volumes, and it would therefore be reasonable to assume that the maximum vehicle type along these routes is either a B-double or a Type 1 road train.

Figure 3.8 presents the combinations of lane width and sealed shoulder width along the WCLT sections, including an assessment of possible compliance with TN155 (based on the assumption noted in the previous paragraph).

**Figure 3.8: Summary of lane width and shoulder width distribution and compliance with TN 155**

| | Length of road (km) for different shoulder widths | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Shoulder width (m)** | **2.9 m** | **3.0 m** | **3.1 m** | **3.2 m** | **3.3 m** | **3.4 m** | **3.5 m** | **3.6 m** | **3.7 m** | **4.0 m** |
| Very narrow (0 – 0.75 ) | – | 4.0 | – | 0.3 | 18.1 | – | 9.1 | 0.4 | – | – |
| Narrow (0.75 – 1.0 ) | – | 0.1 | 0.1 | 1.9 | 8.2 | – | 1.1 | 1.3 | – | – |
| Normal (1.0 – 1.25 ) | – | 5.1 | – | 0.2 | 112.1 | 0.1 | 10.1 | 1.6 | 0.4 | – |
| Wide (1.25 – 1.5 ) | – | 0.7 | 0.7 | 0.7 | 23.0 | – | 2.7 | 0.2 | – | 0.3 |
| Very wide (1.5 – 10 ) | 0.8 | 189.7 | 6.6 | 9.2 | 192.6 | 2.8 | 180.4 | 3.7 | 3.3 | 3.0 |
| **Total (km)** | **0.8** | **199.6** | **7.4** | **12.3** | **354.0** | **2.9** | **203.4** | **7.2** | **3.7** | **3.3** |

Highlighted areas in the table indicate probable compliance with current guidelines, either normal design domain (NDD) or extended design domain (EDD). Highlighted areas indicate 67% (536.6 km) compliance. Exact compliance cannot be determined, as the vehicle type is not available within the dataset. The remaining areas (not highlighted) indicate areas of probable non-compliance. These total length of these sections is 258 km (33% of total length).

The large number of lane and shoulder width combinations across the state suggests that engineers may have made some adjustments to the required width configurations recommended in TN155.

Anecdotal evidence suggests that these adjustments are likely due to either:

- Concerns about shifting the loaded wheel path, which may lead to narrower lane widths.
- Narrower configurations may have been adopted to minimise the movement of edge lines and any possible confusion caused by the removal of the existing edge line (i.e. 7 mm bitumen seal over an existing line, or high-pressure-water line removal, etc.), or
- WCLT implementation prior to the issuing of TN155 in November 2015. It should be noted that this study could not readily identify the date of the WCLT implementation on each road section, due to limitations in the ARMIS data.

## 3.3 Possible pavement issues and causes of failure in WCLT sections

While discussions with pavement engineering practitioners suggested that longer pavement life could be achieved by relocating the loaded wheel path, there are a number of possible pavement failure mechanisms that could occur in situations where a load path has been relocated. These include:

- Differing pavement structures, i.e. thinner pavements with poorer quality materials that form part of the previously untrafficked shoulder.
- Longitudinal joints from a previous shoulder widening project exposed to traffic, especially where the purpose of the widening project was to gain increased untrafficked shoulder width, rather than a continuous and homogeneous pavement structure across the full width of the pavement.
- For unbound granular pavements, untrafficked shoulder areas may experience higher moisture contents leading to increased pavement failure rates when trafficked.
- For bituminous surfaced pavements with higher seal application rates on untrafficked areas (common for shoulder areas), trafficking could cause flushing and subsequent bitumen ‘pick up’, which may lead to loss of surface integrity and subsequent pavement failure.

# 4 STAKEHOLDER FEEDBACK AND SITE VERIFICATION

## 4.1 Stakeholder Feedback

On 27 April 2016, departmental representatives from Cairns, Townsville, Mackay and Rockhampton District offices were invited to comment on pavement issues in relation to WCLTs. A copy of the survey request is provided in Appendix A.

In summary, while the Downs/South West Region believed it was experiencing some pavement issues on the Cunningham Highway (Ipswich – Warwick, section 17B) and the New England Highway (Warwick – Wallangarra, 22C) due to the WCLTs, no other Districts indicated there were any endemic pavement issues associated with these treatments.

## 4.2 Site Verification

In addition to the desktop study conducted using the ARMIS data, a site verification process was also undertaken, which included:

(i) a detailed discussion with departmental representatives from the Darling Downs District and a site investigation that recorded pavement failures within WCLTs along the Cunningham Highway (section 17B) and the New England Highway (section 22C)

(ii) a high level review of WCLT sections in the Cairns, Townsville and Rockhampton Districts.

## 4.3 Findings from the Site Verification

**a) Darling Downs District**

Section 17B of the Cunningham Highway (Ipswich – Warwick) was inspected on 13 May 2016 with the Warwick-based RoadTek Engineer/Manager and the TMR Engineer. There was agreement that the number of pavement failures occuring in the WCLT sections was not excessive when compared to other non-WCLT sections along the road. Nonetheless, the pavement defects and photos were recorded as part of the site investigation. These are provided in Appendix C.

An inspection of section 22C of the New England Highway (Warwick – Wallangarra) was undertaken with the Acting Manager Road Design and the Warwickbased RoadTek Engineer/Manager on Friday 29 July 2016. A total of 17.7 km of WCLTs was inspected.

While this inspection observed a number of pavement failures, they did not appear consistent or sufficiently significant to claim that the treatment was a major contributor to the failure. Moreover, it was also observed that pavements were often 20-to-40years old and also experienced similar failure frequencies in adjacent non-WCLT sections. A summary of the pavement failure extent is provided in Table 4.1 and more details are provided in Appendix D.

It is worth noting that all sections inspected are ‘full-width construction’, with consistent pavement materials and depth across the full pavement width. The only exception to this is between chainage 50.260 km and chainage 52.300 km where there is also a widening and overlay-type cross-section. In this case the outer lane and shoulder exhibit a deeper pavement structure than the old overlaid pavement in the centre of the road.

### b) Cairns

Sections 10N and 10P of the Bruce Highway between Ingham and Innisfail and Innisfail and Cairns were inspected on 20 May 2016. The pavement failures observed at normal travel speed were recorded from the Cairns District.

Very few pavement failures were recorded and no endemic pavement issues were observed. A list of WCLT sections inspected and pavement failures observed is provided in Appendix B.

### c) Townsville and Rockhampton

Small sections of the Bruce Highway in both regions were assessed, with no major pavement failures noted as per advice from regional contacts.

**Table 4.1: Details of inspected locations along New England Highway (22C)**

| Start chainage of WCLT section (km) | End chainage of WCLT section (km) | Length (km) | Average width (m) | Total area ($m^2$) | Type of surfacing | Pavement age (years) | % failures (by area) | % failures (by length of wheelpaths) |
|---|---|---|---|---|---|---|---|---|
| 39.830 | 42.240 | 2.41 | 11 | 26 510 | Seal | 2, 11, 15, 21 | 1.1 | 3.0 |
| 47.080 | 49.400 | 2.32 | 11 | 25 520 | Seal | 21 | 0.2 | 0.5 |
| 50.260 | 52.300 | 2.04 | 11 | 22 440 | Seal | 19, 24 | 1.0 | 2.7 |
| 54.470 | 54.740 | 0.27 | 11 | 2 970 | Seal | 49 | 0.1 | 0.3 |
| 63.480 | 65.240 | 1.76 | 12 | 21 120 | Seal | 29 | 0 | 0 |
| 65.490 | 67.690 | 2.2 | 11 | 24 200 | Seal | 24 | 1.7 | 4.6 |
| 73.560 | 75.640 | 2.08 | 14* | 29 120 | Seal | 27 | 1.1 | 3.9 |
| 87.010 | 91.600 | 4.59 | 12 | 55 080 | Seal | 37 | 1.7 | 5.2 |

* Overtaking lanes in both directions.

# 5 LATERAL WHEEL PATH DISTRIBUTION

The Department requested that the lateral wheel path distribution of heavy vehicles in both WCLT and non-WCLT sections be studied as part of the project. This will allow the Department to better understand the potential impact of the treatments on the pavements.

## 5.1 Significance and Scope of Wheel Path Distribution Investigation

The lateral distribution of wheel loads (i.e. wander) is a common phenomenon observed on roads and airfields. This lateral distribution of wheel loads has long been recognised to have an impact on pavement design thicknesses. A study by Blab and Litzka (1995) identified a number of important factors that influence the wander of vehicle loads. These factors include lane width, vehicle speed, cross-sectional rut-depth and vehicle width. There will be a higher degree of pavement damage accumulated if a vehicle is driving along a path with a smaller degree of lateral wander (i.e. channelised wheel path).

The significance of vehicle wander on pavement design thickness is clear from the 1995 review. A study by Timm and Priest (2005) noted that previous research indicated wheel wander tends to follow a normal distribution with a standard deviation between 0.2 to 0.6 m. An Australian study by Jameson , Sharp and Vertessy (1992) suggested that truck traffic on highways wanders between 0.2 to 0.35 m.

## 5.2 A Review of Available Technology and Cost

During the course of the project, a literature review identified a range of wheel wander detection technologies that have been used in the past. These include:

- traffic-counter tubes
- high-resolution video cameras
- piezoelectric axle sensing strips.

Non-intrusive technologies (i.e. non-permanent installation devices) include the use of precision cameras to vehicles fitted with global positioning systems (GPS). Intrusive technologies (i.e. permanent installation of the sensor on the pavement surface) include different configurations of pneumatic traffic counters, as shown in Figure 5.1. More sophisticated systems, such as the axle sensing devices used by NCAT researchers Timm and Priest (2005), were also used in the past to determine the lateral wheel position and axle load of vehicles. These axle sensors are pressure sensitive strips which are installed directly into either asphalt or concrete. The layout of the sensors is very similar to the configuration used in the pneumatic traffic counters.

Figure 5.1: Example of the use of traffic-counter tubes to determine wheel wander in South Africa.

Source: Professor Wynand Steyn provided this by email on 7 September 2006.

Based on discussions with local suppliers, a cost comparison of different technologies is presented in Table 5.1 . It is noted that the cost of using pneumatic traffic counters is comparable to high resolution video cameras, while the cost of axle pressure sensors such as those used for weigh-in-motion applications is significantly higher.

It is worth noting that while the pneumatic traffic-counter tubes can be an option to determine wheel wander, discussion with a local supplier raised concerns that the flexibility of the pneumatic tube and the latency as compressed air travels inside the tube may not give the level of accuracy required for this project.

Table 5.1: Cost comparison of different technologies investigated

| Technology | Material and installation cost per test site ($) |
|---|---|
| Pneumatic traffic counter | 3 000 |
| High-resolution video camera | 3 000 |
| Axle pressure sensitive strips | 30 000 |

Since the objective of the study was to investigate and measure wheel wander on a number of representative sites across the state, the use of high resolution video cameras was adopted due to their portability, accuracy and lower cost.

## 5.3 Image Processing Technique

The project team worked with the Centre for Intelligent Systems at CQU to develop an image processing technique to determine the vehicle wander. Figure 5.2 shows the basic block diagram of the geometric distance calculation model that was developed. Initially, the method converts the red, green, blue (RGB) image into a grayscale image and extracts the road region. Then, the vehicle region is extracted based on the frame difference. Finally, a target point method extracts the overlap pixel regions and calculates the distance. A more detailed discussion of each step is presented in subsequent sections.

Illustration and sample images for the different image processing steps is shown in Table 5.2. A detailed discussion of the image processing technique can also be found in the CQU research report included in Appendix E.

**Figure 5.2: Image processing technique adopted in the study**

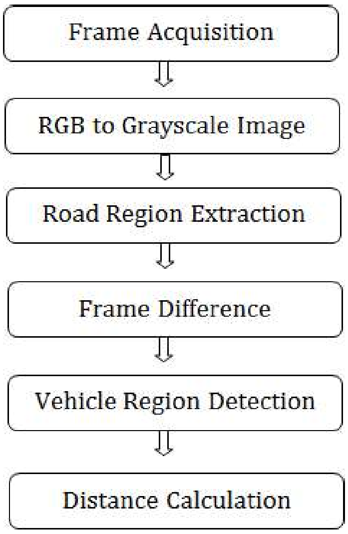
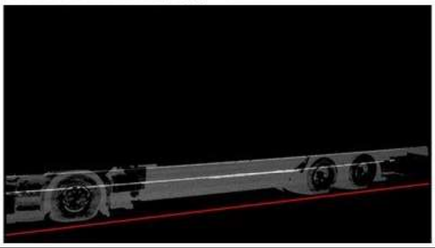



**Table 5.2: Illustrations and sample images for different image processing steps**

| Image processing steps | Sample images |
|---|---|
| Frame acquisition |  |
| RGB to grayscale image |    |
| Road region extraction | |

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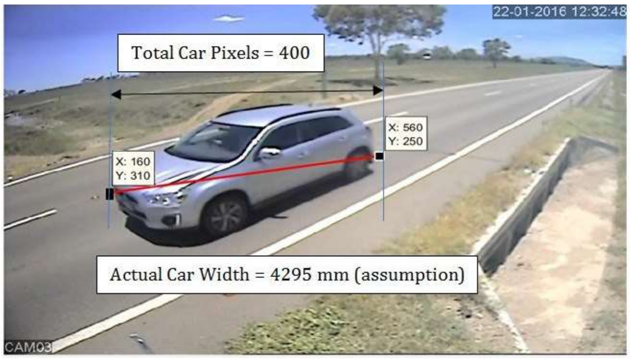
<tr><td>Frame difference</td><td>
</td></tr>
<tr><td>Vehicle region detection</td><td>
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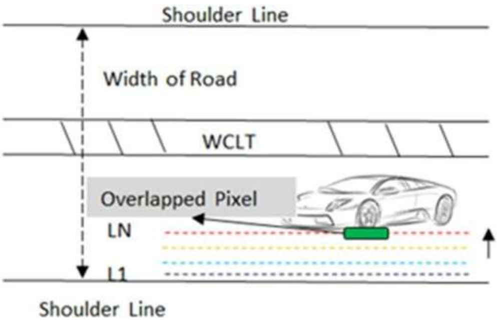
<tr><td>Distance calculation</td><td>
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## 5.4 Selection of Test Sites

The objective of the wheel wander study was to find out if the lane geometric configuration (i.e. single median/non-WCLT and WCLT median) has an influence on the lateral distribution of vehicle wheel paths. Based on discussions with representatives from the districts and the list of WCLT locations across Queensland, the project team selected two Regions, namely Mackay and Warwick, for field trials. Six sites were selected. When selecting the test sites, consideration was given to the geometric alignment, road widths, daily traffic and percentage of heavy vehicles at each site.

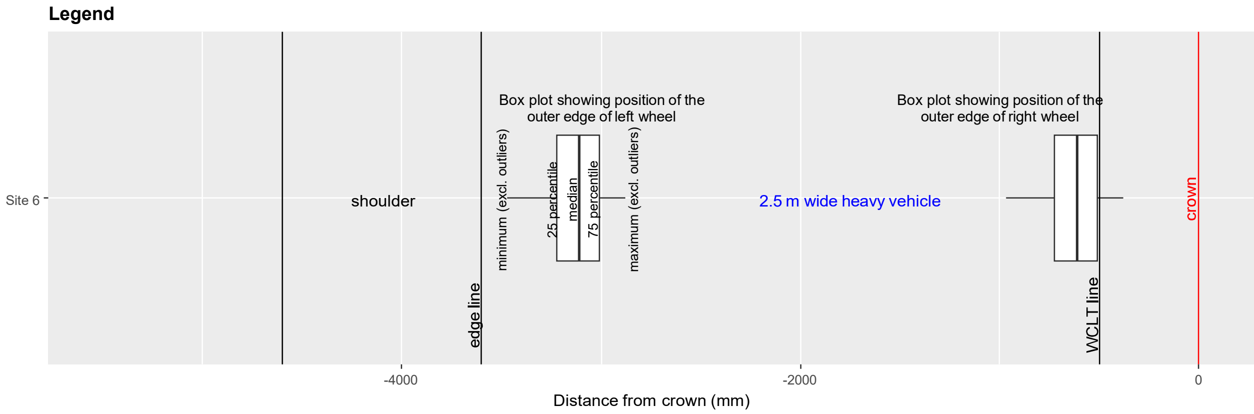
Table 5.3 provides a summary of the lane geometric configuration and traffic data associated with each of the six test sites. Figure 5.3 presents the geometric configuration information as a legend. Figure 5.4 and Figure 5.5 show the locations of the test sites with different colour markers used to denote single and WCLT lane configurations.

The analysis only includes results for heavy vehicles. Light vehicles have been ignored. All test sites are located on straight and flat segments of the road to minimise the effect of horizontal and vertical curves in the analysis.

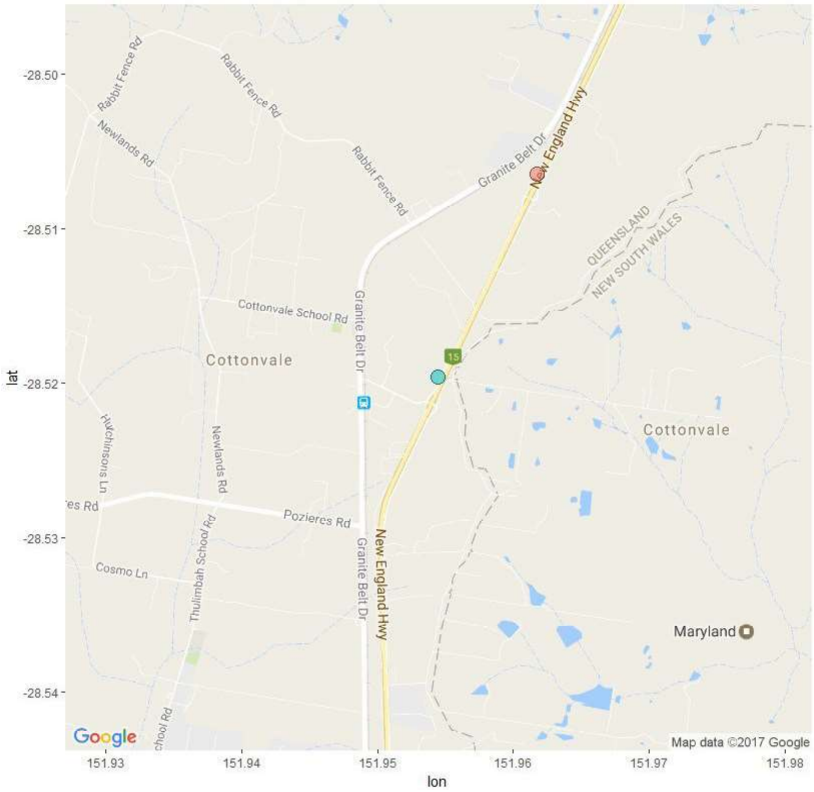
### Table 5.3: Traffic and basic lane geometric details for the six test sites in the Mackay and Warwick districts

| Region | Site (road) | Centreline configuration | Chainage (km) | 2-way AADT in 2015 | %HV | Lane width (m) | Shoulder width (m) |
|---|---|---|---|---|---|---|---|
| Mackay | Site 1 (10G) | Non-WCLT | 53.75 | 2 156 | 30 | 3.26 | 0.90 |
| | Site 2 (10G) | WCLT | 47.70 | 2 156 | 30 | 2.91 | 1.65 |
| | Site 3 (10G) | Non-WCLT | 82.14 | 3 461 | 23 | 3.35 | 1.50 |
| | Site 4 (10G) | WCLT | 93.77 | 3 461 | 23 | 2.90 | 1.10 |
| Warwick | Site 5 (22C) | Non-WCLT | 42.67 | 3 648 | 20 | 3.0 | 1.40 |
| | Site 6 (22C) | WCLT | 41.10 | 3 648 | 20 | 3.6 | 0.60 |

### Figure 5.3: Legend for the lane geometric configuration

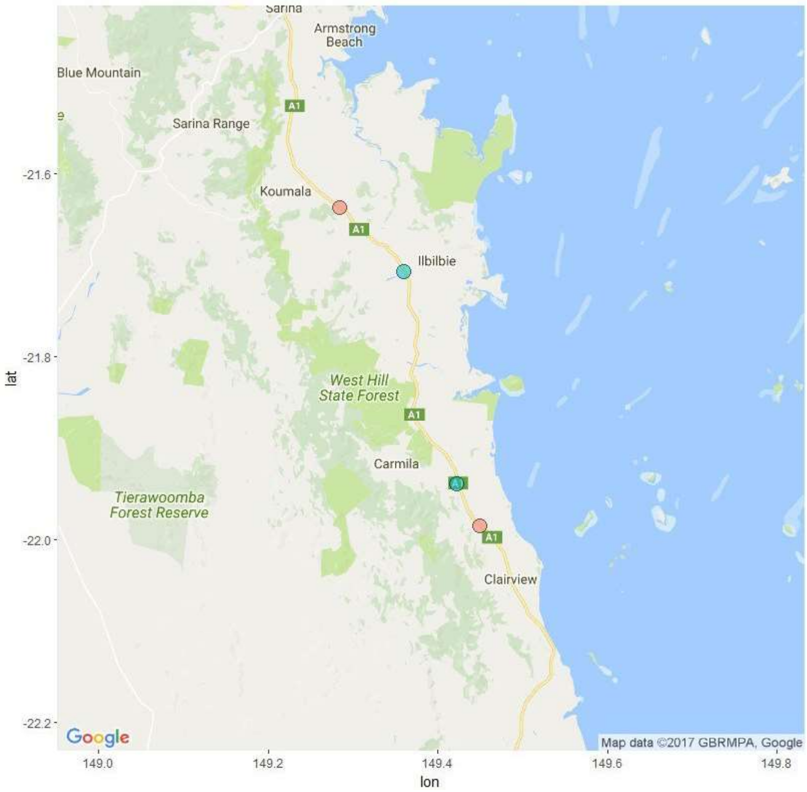



### Figure 5.4: Location of test sites in the Warwick district along the New England Highway (22C)




Source: Google Maps (2017), 'Queensland', map data, Google, California, USA.

Figure 5.5: Location of test sites in the Mackay district along the Bruce Highway (10G)




Source: Google Maps (2017), 'Queensland', map data, Google, California, USA.

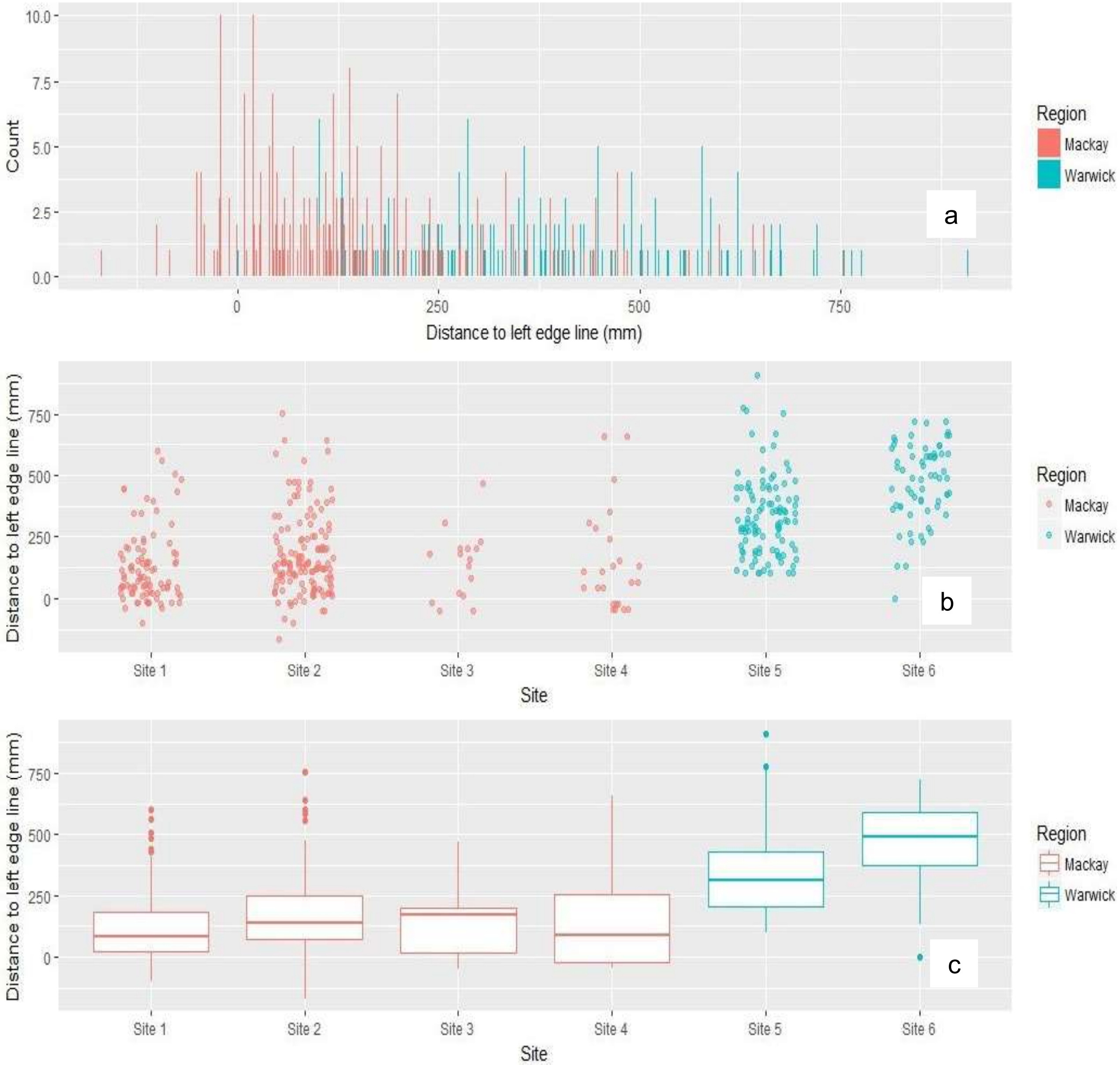
## 5.5 Test Results and Analysis

Details of the data collected as part of the wander image analysis are included in the CQU report ( Appendix E). The report includes information such as the analysis technique, wander information collected at each site, and lane geometric information.

Based on the data presented in the CQU report, further statistical analysis has been undertaken as part of the study to investigate the effect of WCLTs on vehicle wander. In this analysis, wander refers to the distance between the edge of the left vehicle wheel and the edge line. The location of the edge line is taken as the zero reference datum. For example, a higher positive wander value means the left wheel is further towards the centreline. A negative value means that the edge of the left wheel is located in the shoulder, to the left of the shoulder edge line.

Figure 5.6 displays four different statistical plots across the six test sites. Figure 5.6(a) shows the histogram of the lateral positions measured across the Mackay and Warwick sites. The vehicle paths at the Mackay sites are more channelised when compared to the Warwick sites.
Figure 5.6(b) contains scattered plots showing the lateral positions in each of the six sites. When considering the effects of non-WCLT vs WCLT sections, it is important to inspect the data in pairs (i.e. Site 1 vs Site 2, Site 3 vs Site 4, and Site 5 vs Site 6). Figure 5.6(c) shows the box plot where different colours are used to distinguish between the Mackay and Warwick sites.

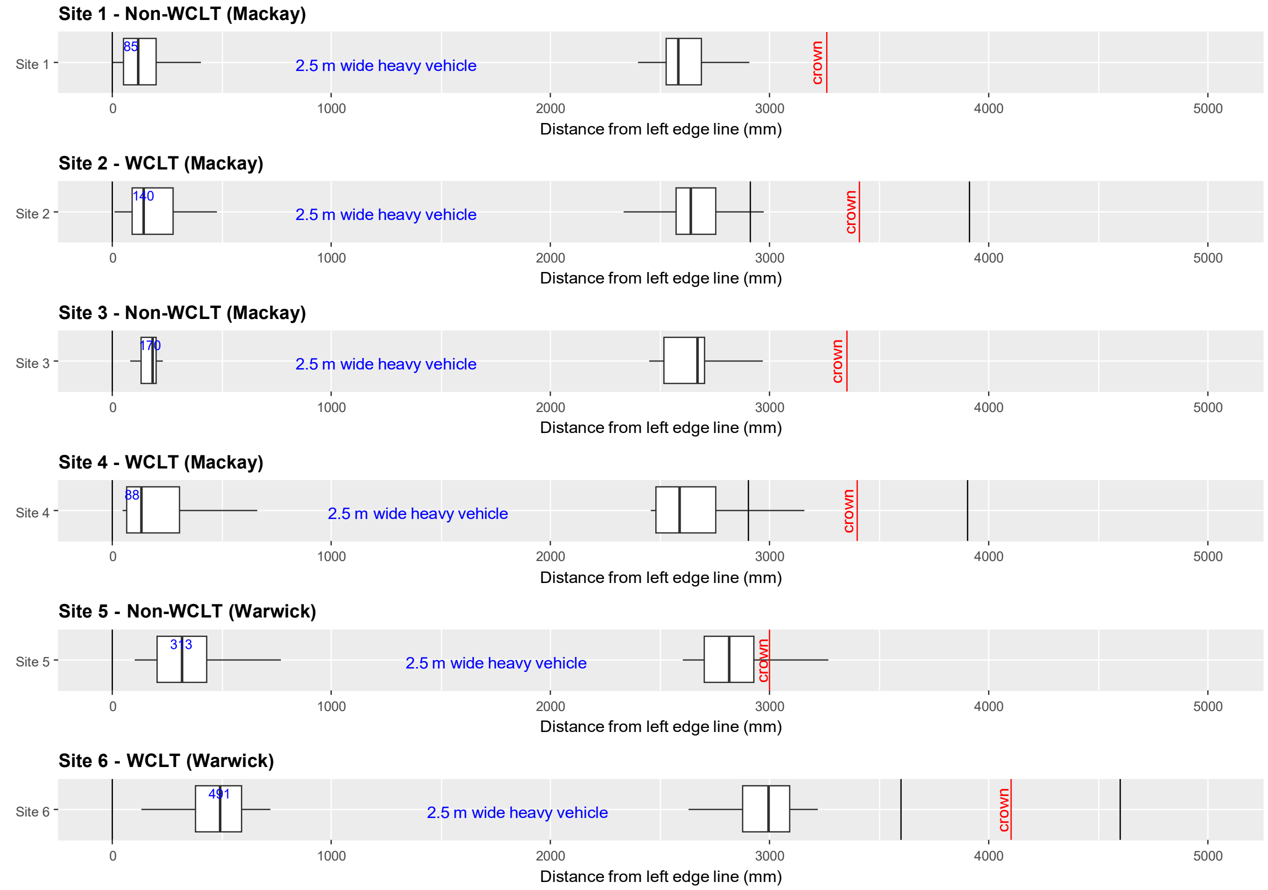
**Figure 5.6: Statistical plots of vehicle wander data collected in all six sites located across the Mackay and Warwick districts**




To better understand the lateral position of the heavy vehicle in relation to the edge line and crown position, the box plot showing the distance from the wheel to the edge line is presented in Figure 5.7 (refer to Figure 5.3 for the legend). A summary of the distance is also presented in Table 5.4.

The median distance from the edge line is generally higher in the WCLT sites than the non-WCLT sites. This is an interesting finding because this observation is contrary to the common belief that heavy vehicles will travel closer to the left edge line after the installation of a WCLT. The observation suggests that the extra space provided by the 1.0 m WCLT median results in additional separation distance between oncoming vehicles and allows the drivers of heavy vehicles to be more confident to travel closer to the median.

## Figure 5.7: Wheel positions and distance from the left edge line




Note: A maximum heavy vehicle width of 2.5 m has been adopted based on dimensions provided by National Heavy Vehicle Regulator (2016).

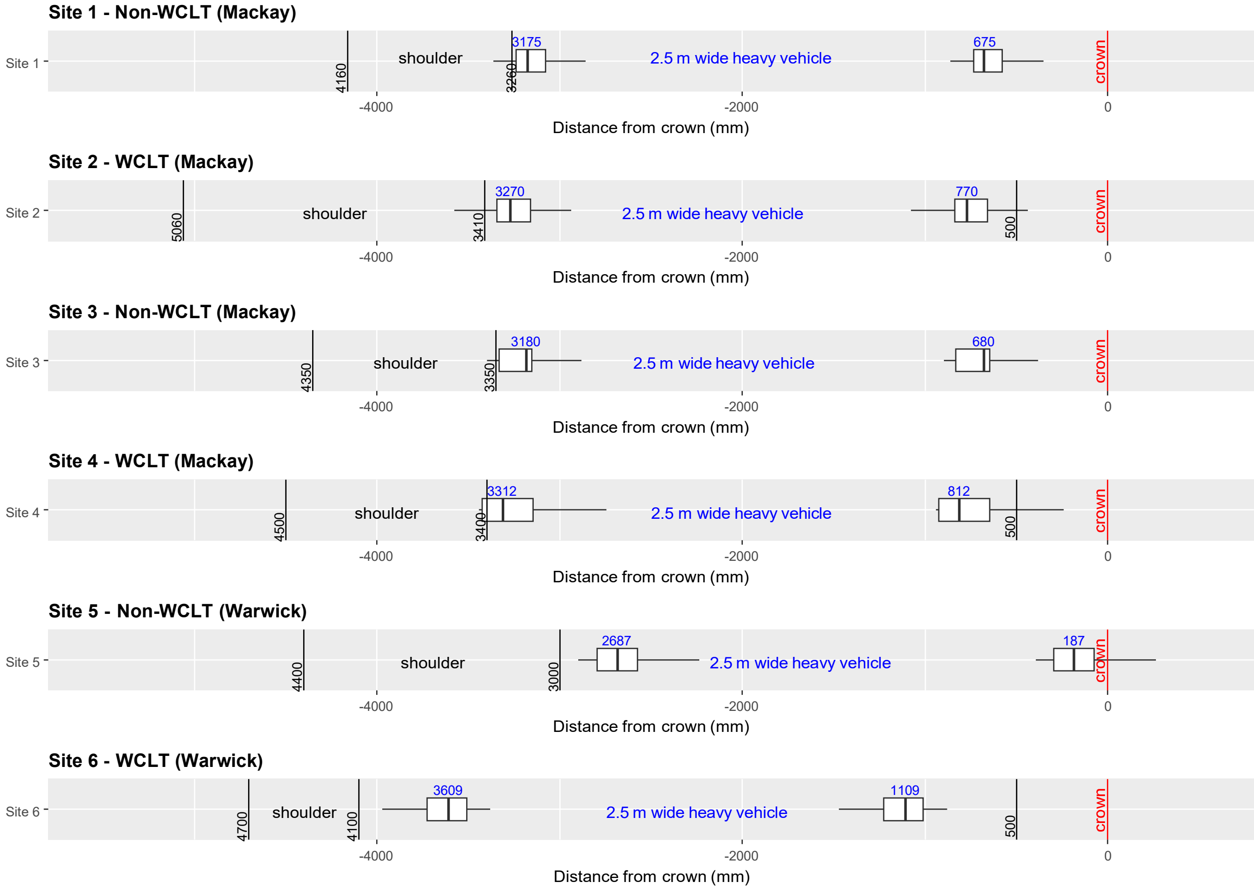
## Table 5.4: Summary of distance between edge line and outer edge of left wheel

| | Centre line type | Lane width (mm) | Sealed shoulder width (mm) | 25th percentile (mm) | Median (mm) | 75th percentile (mm) | 75th – 25th percentile (mm) |
|---|---|---|---|---|---|---|---|
| Site 1 (Mackay) | Non-WCLT | 3 260 | 900 | 24.6 | 84.7 | 183.1 | 158.5 |
| Site 2 (Mackay) | WCLT | 2 900 | 1 650 | 70.0 | 139.5 | 250.6 | 180.6 |
| Site 3 (Mackay) | Non-WCLT | 3 350 | 1 500 | 17.5 | 170.0 | 200.0 | 182.5 |
| Site 4 (Mackay) | WCLT | 2 900 | 1 100 | -21.9 | 87.6 | 251.9 | 273.8 |
| Site 5 (Warwick) | Non-WCLT | 3 000 | 1 400 | 202.5 | 313.2 | 427.8 | 225.3 |
| Site 6 (Warwick) | WCLT | 3 600 | 600 | 490.5 | 490.5 | 588.6 | 98.1 |

Other observations from the above data can be made. In Mackay where there is a non-WCLT configuration (Site 1 and Site 3), the average median distance between the edge line (EL) and the outer edge of the left tyre is 128 mm. Where there is a WCLT configuration (Site 2 and Site 4), the average median distance between the edge line and the outer edge of the left tyre is 114 mm. For Mackay sites, the distance from the edge line on average has not significantly changed between WCLT and non-WCLT configurations. Lane width and shoulder width appear to have little effect on the average tyre position in relation to the edge line. For the Warwick sites, heavy vehicles tend to travel further away from the edge line than in the non-WCLT sections.

The same set of data can also be presented in a different way by mapping the distance of the wheel to the crown, as shown in Figure 5.8. A summary of the distances is also presented in Table 5.5. This shows the right edge of the wheel in relation to the crown.

**Figure 5.8: Wheel positions and distance from the road crown**




The data suggests that, as commonly expected, all WCLT sections have the right edge of the wheel travelling further away from the crown. This can be partially explained by the additional 0.5 m width provided by the WCLT. The difference is significant between Site 5 and Site 6, but this can be caused by the significant difference in lane width and the fact that the data collected at Site 6 is at the start of a taper leading to a left-hand slip lane.

For Mackay, the average median distance between the crown and the outer edge of the right wheel for the non-WCLT sections is 678 mm. On the other hand, the average median distance for the WCLT sections is 791 mm. The difference is only 113 mm and is insignificant in relation to the tyre width.

**Table 5.5: Summary of distances between the crown and the outer edge of the right wheel**

| | Centre line type | Lane width (mm) | Sealed shoulder width (mm) | 25th percentile (mm) | Median (mm) | 75th percentile (mm) | 75th – 25th percentile (mm) |
|---|---|---|---|---|---|---|---|
| Site 1 (Mackay) | Non-WCLT | 3260 | 900 | 577.0 | 675 | 735.4 | 158.4 |
| Site 2 (Mackay) | WCLT | 2900 | 1650 | 659.5 | 770 | 840.0 | 180.5 |
| Site 3 (Mackay) | Non-WCLT | 3350 | 1500 | 650.0 | 680 | 832.5 | 182.5 |
| Site 4 (Mackay) | WCLT | 2900 | 1100 | 648.2 | 812 | 921.9 | 273.7 |
| Site 5 (Warwick) | Non-WCLT | 3000 | 1400 | 502.2 | 247 | 727.5 | 225.3 |
| Site 6 (Warwick) | WCLT | 3600 | 600 | 511.4 | 1109 | 724.1 | 212.7 |

In summary, the median distance from the edge line is generally higher in the WCLT sites than the non-WCLT sites. This is an interesting finding because this observation is contrary to the common belief that heavy vehicles will travel closer to the left edge line after the installation of a treatment. For Mackay sites, the distance from the edge line on average has not significantly changed between WCLT and non-WCLT sites. Lane width and shoulder width appear to have little effect on the tyre position in relation to the edge line. For the Warwick sits, heavy vehicles tend to travel further away from the edge line than in the non-WCLT sections. The data suggested that, as commonly expected, all WCLT sections have the right edge of the wheel travelling further away from the crown.

The reason for the difference in behaviour in the Mackay and Warwick sites is unclear. It is suspected that factors such as lane width, shoulder width, the presence of a slip lane, and the position of the camera can influence the results. Future research should expand the number of test sites to ascertain the influence of these factors in a more controlled manner.

# 6 RETROFITTING WCLTS TO EXISTING PAVEMENTS DESIGN DUE DILIGENCE: PAVEMENT IMPACT REVIEW

Where it is proposed that a WCLT be retrofitted to an existing pavement in accordance with Technical Note TN155, it is recommended that a pavement 'due diligence' be undertaken.

It is recommended that the designer review a range of information sources (outlined below) at a desktop level prior to undertaking a validating field visit to confirm the level of risk to the pavement as a result of a WCLT.

If there are doubts that the pavement immediately outside the existing lane line (+0.25 m) is likely to be damaged as a result of a WCLT, this should be further discussed with the Department.

Note that this due diligence review should be undertaken in the context and scope of a low-cost minor linemarking WCLT. Accordingly, it is not intended to include geotechnical investigations to confirm pavement depths and material types, where the investigation costs would readily exceed the cost of the treatment itself.

However, the Department may undertake limited geotechnical investigations in some situations, where there are concerns about adverse impacts on the pavement performance as a result of the treatment.

The recommended minimum information that could be reviewed for the pavement due diligence includes:

(a) Previous construction plans (cross-sections, pavement plans and details, theoretical location of pavement joint for widening projects).

(b) ARMIS/Chartview data: lane and shoulder pavement depths.

(c) ARMIS/Chartview data: project history, i.e. widening or full-width road construction etc.

(d) ARMIS/Chartview data: rutting and roughness values. Sections with high rutting and roughness values may not be suitable for a WCLT.

(e) ARMIS/Chartview data: pavement maintenance history.

(f) If possible, spray rates or other anecdotal evidence from the Department to determine if higher spray rates may have occurred on the previously untrafficked shoulder. Higher binder application rates may increase the risk of flushing or binder 'pick up' that could contribute to surfacing/pavement distress.

(g) Field investigation, including

   i. road condition
   ii. crossfall (continues good crossfall across shoulder, no major subgrade swelling causing very flat shoulder which may be a higher risk for poor pavement performance if the OWP moves further out)
   iii. rutting profile and shoving defects; sections in poor condition may be at a higher risk of pavement failure
   iv. pavement repairs
   v. surface condition: shoulder seal condition compared to lane seal condition
   vi. if the road was previously widened, confirm the location of the longitudinal joint so as to ensure the zone of the new outer wheel path does not coincide with the pavement joint

(h) Confirm general subgrade type and support conditions.

# 7 CONCLUSIONS AND RECOMMENDATIONS

## 7.1 Desktop study and site verifications

In the last two-to-three years, the Department has trialled and implemented a 1 m WCLT to minimise the risk of head-on crashes. Treatment guidelines were developed and the Department issued an interim Technical Note TN155 in November 2015. This provides guidance on the geometric design of WCLTs in Queensland. To implement a treatment, often the edge line is moved outwards to continue to provide sufficient lane width. Some districts reported that WCLT sections have experienced additional pavement failures and it was hypothesed that the WCLT had contributed to the cause of failure.

The purpose of this study was to establish the status of WCLTs on the Department's road network and identify whether any significant pavement issues have been caused by their implementation. The Department also requested that the study establish the distribution of heavy vehicle wheel paths in different line marking configurations for both WCLT and non-WCLT (i.e. single-line median) arrangements. The study reviewed a number of sealed lane/shoulder width combinations. It also engaged researchers at CQU to investigate the use of an automated image processing technique to monitor heavy vehicles on a number of WCLT and non-WCLT configurations.

During the project, the ARMIS data collected in June 2016 showed that the Department had implemented 370 continuous segments, providing a total of 795 km of WCLT sections in seven districts along 14 different highways. Over 75% of these sections are located on the Bruce Highway, with 50% occurring in two Districts, i.e. Mackay/Whitsunday and Fitzroy. Treatments have been implemented on two-way, two-lane rural highways in 100 km/h environments with traffic volumes > 1000 vehicles per day. One-third of these sections have traffic volumes of more than 5000 vehicles per day.

While discussions with pavement engineering practitioners suggested that longer pavement life could be achieved by relocating the loaded wheel path, it was also acknowledged there are a number of possible pavement failure mechanisms that could occur in situations where a load path has been relocated.

In response to a survey on pavement issues in relation to WCLTs , while the Darling Downs District believed that it was experiencing some pavement issues on the Cunningham Highway (Ipswich – Warwick, Section 17B) and the New England Highway (Warwick – Wallangarra, Section 22C) , no other districts indicated that there were any endemic issues as a result of the treatments.

A site investigation indicated that the number of pavement failures observed on Section 17B of the Cunningham Highway was not excessive when compared to other non-WCLT sections. The site investigation along Section 22C of the New England Highway identified a number of pavement failures, however these failures did not appear consistent or sufficiently significant to prove the hypothesis that the WCLT was a major contributor to the failures observed. Moreover, it was also observed that the pavements were often 20-to-40-years old and experienced similar failure frequencies in adjacent non-WCLT sections.

A site visit was also undertaken along Section 10 N (Ingham – Innisfail) and Section 10P (Innisfail – Cairns) of the Bruce Highway. Very few pavement failures were noted and no endemic pavement issues associated with the WCLTs were observed. Small sections of the Bruce Highway near Townsville were also viewed with no major pavement failure issues noted, as per advice received from regional contacts.

In summary, the study did not find significant impacts of the WCLTs on the performance of the pavement over the short-term period since the treatments were first introduced in Queensland.

## 7.2 Study of wheel wandering

The Department also requested that the wheel path distribution for heavy vehicles in both WCLT and non-WCLT sections be studied as part of the project, enabling the Department to better understand the potential impact of the treatments on pavements. One of the objectives was to develop a cost-effective method to track the lateral distribution of vehicle wheel paths in WCLT and non-WCLT road sections. Technologies such as traffic-counter tubes, high-resolution cameras and piezoelectric axle sensing strips were investigated. It was found that the high-resolution video camera was the most appropriate technology for the study.

A number of field trials at six different sites in the Warwick and Mackay districts were conducted in collaboration with researchers from CQU.

In summary, the mean distance from the edge line is generally higher in the WCLT sites than the non-WCLT sites. This is an interesting finding because this observation is contrary to the common belief that heavy vehicles will travel closer to the left edge line after the treatment. For Mackay sites, the distance from the edge line on average did not significantly change between WCLT and non-WCLT sites in relation to the width of the tyre. Lane width and shoulder width appear to have little effect on the average tyre position in relation to the edge line. For the Warwick data, heavy vehicles tend to travel further away from the edge line than in the non-WCLT sections. The data suggested that, as commonly expected, all WCLT sections have the right edge of the wheel travelling further away from the crown.

## 7.3 Recommendations

Some changes to TN155 are recommended to ensure a pavement due diligence is undertaken before a treatment is implemented along a section of road. The due diligence should review pavement configurations, project history and condition data from ARMIS/Chartview. Depending on the findings, additional field investigation may be warranted.

The reason for the difference in behaviour in the Mackay and Warwick sites is unclear. It is suspected that factors such as lane width, shoulder width, presence of a slip lane, and the position of the camera can influence the results. Future research should expand the number of test sites to ascertain the influence of these factors in a more controlled manner.

# REFERENCES

Blab, R & Litzka, J 1995, 'Measurements of the lateral distribution of heavy vehicles and its effects on the design of road pavements', *International Symposium on Heavy Vehicle Weights and Dimensions, 4th, 1995, Ann Arbor, Michigan, USA*, University of Michigan, Ann Arbor, Michigan, pp. 389 - 395.

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National Heavy Vehicle Regulator 2016, *National heavy vehicle mass and dimension limits*, NHVR, Brisbane, Qld, viewed 25 July 2017, <https://www.nhvr.gov.au/files/201607-0116-mass-and-dimension-limits.pdf>.

*Queensland Department of Transport and Main Roads 2015, *Wide centre line treatment: interim advice,* technical note 155, TMR, Brisbane, Qld.

Timm, D & Priest, A 2005, *Wheel wander at the NCAT test track*, report 05-02, National Center for Asphalt Technology, Auburn, Alabama, USA.

**TN155 was withdrawn in December 2019 and incorporated in the Supplement to Austroads Guide to Road Design, the Road Planning and Design Manual, Volume 3 (August 2018).*

# APPENDIX A STAKEHOLDER FEEDBACK REQUEST (27/4/2016)

**Phil Hunt**

| | |
|---|---|
| **From:** | Phil Hunt <phil@roadeng.com.au> |
| **Sent:** | Wednesday, 27 April 2016 12:23 PM |
| **To:** | 'david.g.hamilton@tmr.qld.gov.au'; 'alan.j.andersen@tmr.qld.gov.au'; 'Brendan J Day'; 'paul.m.shelton@tmr.qld.gov.au'; 'andrew.h.thomas@tmr.qld.gov.au'; 'suzanne.h.brown@tmr.qld.gov.au' |
| **Cc:** | 'Andrew Beecroft'; 'Jeffrey Lee (Dr)'; 'Daniel Boshier'; 'jothi.m.ramanujam@tmr.qld.gov.au'; 'Peter A Evans' |
| **Subject:** | TMR/ARRB - Effects of Wide Centre Line Treatment on Pavements - Initial feedback from Districts |
| **Attachments:** | State WCLT Sections - first pass.xlsx |

Dear Colleagues

As discussed with some of you recently, TMR/ARRB are undertaking a brief review of the effects (if any) of WCLTs on pavements.
The project has been approved by Deputy Chief Engineer Peter Evans, after being raised with him by a region/district and subsequently Head Office representatives.
I have been engaged to assist the project.
(To those I have unsuccessfully phoned, I apologise if you are not the right person, please pass this onto the relevant person in your district – thanks)

The main issue being investigated is the movement or location of the OWP after WCLT, and whether this has anecdotally has caused any pavement failures?
Do you have any concerns? Major/minor?

We are seeking basic feedback by Friday 6th May 2016, or earlier if possible.

In particular, an issue has been raised where the WCLT has moved the edge line 0.25m further out when compared with the pre-existing edge line.
It is claimed that this has caused pavement failures and issues. These are yet to be investigated and quantified.

As a first pass exercise in this review, we are seeking any comment you may have at this early stage.
In particular :

(1) Have you noticed any increase in pavement failures in sections where you have moved the edge line/OWP for WCLT treatments? Can they be attributed to the WCLT?
(2) Have you deliberately decided not to move edge line (ie 3.0m lane only) so as to avoid any pavement risk? Approximately how many kms/% of treatments would be in this category?

I have attached a data dump from Armis with some summary Pivot Tables for your information.
You can easily filter or extract your roads from this information, if needed.
A summary of WCLTs by Road ID :

| Row Labels | Sum of Length |
|---|---|
| 10A | 1.78 |
| 10B | 42.171 |
| 10C | 67.171 |
| 10D | 92.77 |
| 10E | 50.006 |
| 10F | 44.243 |
| 10G | 70.533 |
| 10H | 88.627 |
| 10J | 28.978 |
| 10K | 7 |
| 10L | 7.947 |
| 10M | 30.318 |
| 10N | 59.019 |
| 10P | 14.613 |
| 150B | 7.5 |
| 16A | 50.24 |
| 16B | 29.609 |
| 17B | 18.85 |
| 22C | 17.82 |
| 28B | 1.96 |
| 32A | 2.86 |
| 33B | 19.432 |
| 340 | 1 |
| 342 | 0.52 |
| 40A | 20.693 |
| 40C | 2.465 |
| 42A | 0.998 |
| 454 | 5.16 |
| 490 | 11.06 |
| **Grand Total** | **795.343** |

Do not hesitate to contact me, if you wish to discuss further.

Cheers
Yours in Pavements

Kind Regards

Phil Hunt
Director, Principal Engineer
0413 762 126
www.roadeng.com.au

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# APPENDIX B CAIRNS SITE INSPECTION – MAY 2016

WCLT – 10N and 10B (Bruce Highway) field inspection 20/5/2016, performed at 80-100 km/h (normal traffic speed)

| Road | Start_Tdist | End_Tdist | Length | Surface | Pavement Failures | ATLM |
|---|---|---|---|---|---|---|
| 10P | 19.8 | 20.3 | 0.5 | Seal | No | Yes |
| 10P | 20.3 | 21.81 | 1.51 | Seal | No | No |
| 10P | 23.13 | 23.9 | 0.77 | Seal | No | Yes |
| 10P | 23.9 | 25.22 | 1.32 | Seal | No | No |
| 10P | 25.22 | 25.92 | 0.7 | Seal | No | Yes |
| 10P | 31.2 | 32.08 | 0.88 | Seal | 100m rutting/shoving on new Edge Line LHS | No |
| 10P | 32.08 | 32.81 | 0.73 | Seal | No | Yes |
| 10P | 32.81 | 36.11 | 3.3 | Seal | No | No |
| 10P | 37.36 | 40.16 | 2.8 | Seal | No | No |
| 10P | 44.1 | 45.66 | 1.56 | Seal | No | Partial |
| 10P | 57.91 | 60.4 | 2.49 | Seal | No | No |
| 10P | 60.4 | 61.46 | 1.06 | Seal | No | No |
| 10N | 39.03 | 40.6 | 1.57 | Seal | No | No |
| 10N | 47.7 | 51.3 | 3.6 | Seal | No | Partial |
| 10N | 55.3 | 66 | 10.7 | Asphalt and Seal | No | Partial |
| 10N | 68 | 68.38 | 0.38 | Seal | No | No |
| 10N | 69.08 | 73.2 | 4.12 | Seal | 72.2-72.3 : Rut | Partial |
| 10N | 74.5 | 77.7 | 3.2 | Seal | No | Partial |
| 10N | 79.175 | 89 | 9.825 | Asphalt and Seal | No | Partial |
| 10N | 89 | 90.628 | 1.628 | Seal | No | Yes |
| 10N | 90.628 | 92.278 | 1.65 | Asphalt and Seal | No | Yes |
| 10N | 92.6 | 93.318 | 0.718 | Seal | No | No |
| 10N | 93.318 | 93.98 | 0.662 | Seal | No | Yes |
| 10N | 102.91 | 103.47 | 0.56 | Seal | No | No |
| 10N | 103.47 | 104.23 | 0.76 | Seal | No | Yes |
| 10N | 104.23 | 104.6 | 0.37 | Seal | No | No |
| 10N | 104.6 | 104.97 | 0.37 | Seal | No | Yes |
| 10N | 104.97 | 105.3 | 0.33 | Seal | No | No |
| 10N | 105.3 | 109.477 | 4.177 | Seal | No | Yes |
| 10N | 109.72 | 113.83 | 4.11 | Seal | No | No |
| 10N | 113.83 | 114.302 | 0.472 | Seal | No | Yes |
| 10N | 114.302 | 116.2 | 1.898 | Seal | No | No |
| 10N | 117.49 | 118 | 0.51 | Seal | No | No |
| 10N | 118 | 118.37 | 0.37 | Seal | No | Yes |
| 10N | 118.37 | 119 | 0.63 | Asphalt | No | Yes |
| 10N | 119 | 119.517 | 0.517 | Seal | No | No |
| 10N | 136.39 | 137.13 | 0.74 | Seal | No | Yes |

Note 1: Edge line was generally observed as moved to new location - see photos

10N WCLT 60.616 a

10N WCLT 60.616 b

10N WCLT 71.000 a

10N WCLT 81.510 a

10N WCLT 81.510 b

10N WCLT 81.510 c

10N WCLT 91.096 a

10N WCLT 91.096 b

10N WCLT a

10N WCLT b

10N WCLT c

10N WCLT d

# APPENDIX C DARLING DOWNS – CUNNIGHAM HIGHWAY (17B) SITE INSPECTION – MAY 2016

WCLT – 17B (Cunningham Highway) field inspection 13/5/2016, performed at 80-100 km/h (normal traffic speed)

| Road | Start_Tdist _WCLT | End_Tdist _WCLT | Length | Area of Pavement | Surface | Pavement Failures - Left Lane Assessed (Only) | Area of Pavement Failures |
|---|---|---|---|---|---|---|---|
| 17B | 91.5 | 95.62 | 4.12 | 43,260 | Seal | Minor : 92.15 5m x 1m x2 sites; 94.86 1m; 95.08 x1m | 12 |
| 17B | 96.65 | 97.2 | 0.55 | 5,775 | Seal | Minor : 96.71 5m x 1m; | 5 |
| 17B | 97.84 | 101.45 | 3.61 | 37,905 | Seal | Minor : 98.36 3mx 1m; 99.43 x 1m; 100.91 x1m; 100.96 5m x 1m; 101.34 - 101.50 5mx1mx3sites | 25 |
| 17B | 101.94 | 105.95 | 4.01 | 42,105 | Seal | Minor : 104.67 x1m; 105.02 x1m; 105.9 x1m | 3 |
| 17B | 106.21 | 107.54 | 1.33 | 15,162 | Seal | Minor : 106.42 5m x 1m; 106.74-106.82 3m x 1mx5sites; 106.9 5mx1m; 107.183mx1m; 107.28 3mx1m; | 29 |
| 17B | 108.01 | 110.3 | 2.29 | 25,648 | Seal | Minor : 108.26 x1m; 109.68 x1m; 109.89 x1m | 3 |
| 17B | 110.3 | 114.15 | 3.85 | 43,120 | Asphalt | Nil | 0 |
| | | TOTAL | 19.76 | 212,975 | | | 77 |
| | Total Wheelpath Length (km) | | 79.04 | | | Wheelpath Length Failed (m) | 77 |
| | | | | | | Total Wheelpath Failure experienced | 0.10% |

**Width Checks**

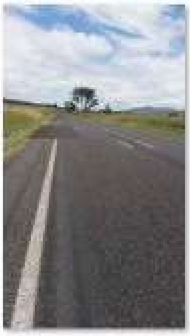
| Chge | LHShldr | Left Lane | WCLT | Right Lane | RH Shldr | TOTAL |
|---|---|---|---|---|---|---|
| 98.36 | 1.3 | 3.5 | 1.0 | 3.3 | 1.4 | 10.5 |
| 106.56 | 1.8 | 3.4 | 1.0 | 3.3 | 1.9 | 11.4 |
| 109.53 | 1.8 | 3.3 | 1.0 | 3.3 | 1.8 | 11.2 |


17B WCLT - photo provided by TMR District a


17B WCLT - photo provided by TMR District b


17B WCLT - photo provided by TMR District c


17B WCLT - photo provided by TMR District d


17B WCLT - photo provided by TMR District e


17B WCLT 92.34 a


17B WCLT 92.34 b


17B WCLT 93.15 a


17B WCLT 93.15 b


17B WCLT 93.15 c


17B WCLT 93.15 d


17B WCLT 93.15 e


17B WCLT 98.35 a


17B WCLT 98.35 b


17B WCLT 98.35 c


17B WCLT 98.35 d


17B WCLT 98.35 e


17B WCLT 106.56 a


17B WCLT 106.56 b


17B WCLT 109.53 a


17B WCLT 109.53 b

# APPENDIX D DARLING DOWNS – NEW ENGLAND HIGHWAY (22C) WARWICK TO WALLANGARRA – JULY 2016

WCLT - 22C New England Highway (Warwick - Wallangarra) Field inspection 29/7/2016

Log of Failures

| Road | Start_Tdist _WCLT | End_Tdist _WCLT | Length | Lane | Location of Failure | Width | Area of Failure (m2) | Surface | Failure Type | Pavement Construction | ATLM |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 22C | 39.830 | 42.240 | 2.41 | | SECTION 1 | 11 | 26,510 | Seal | Pavement Age 21, 2, 15, 11 Years | Full Width pavement | |
| 22C | 39.880 | 39.885 | 0.005 | 1 | OWP | 1.2 | 6 | Seal | Rut/Shove | | No |
| 22C | 39.910 | 39.930 | 0.02 | 1 | OWP | 3.5 | 70 | Seal | Patch ( Remove/Replace) | | No |
| 22C | 40.460 | 40.490 | 0.03 | 2 | OWP | 1.2 | 36 | Seal | Rut/Shove | | No |
| 22C | 40.590 | 40.610 | 0.02 | 2 | OWP | 1.2 | 24 | Seal | Rut/Shove | | No |
| 22C | 40.710 | 40.730 | 0.02 | 2 | OWP | 1.2 | 24 | Seal | Rut/Shove | | No |
| 22C | 41.000 | 41.006 | 0.006 | 2 | OWP | 1.2 | 7 | Seal | Rut/Shove | | No |
| 22C | 41.010 | 41.013 | 0.003 | 2 | OWP | 1.2 | 4 | Seal | | | No |
| 22C | 41.030 | 41.040 | 0.01 | 2 | OWP | 1.2 | 12 | Seal | | | No |
| 22C | 41.160 | 41.170 | [redacted] | 1 | Lane | 3.5 | 0 | Seal | OLD PATCH - not recorded as current failure | | No |
| 22C | 41.200 | 41.220 | 0.02 | 2 | OWP | 1.2 | 24 | Seal | | | No |
| 22C | 41.470 | 41.490 | 0.02 | 1 | OWP | 1.2 | 24 | Seal | | | No |
| 22C | 41.550 | 41.590 | 0.04 | 1 | OWP | 1.2 | 48 | Seal | | | No |
| 22C | 41.720 | 41.725 | 0.005 | 1 | OWP | 1.2 | 6 | Seal | | | No |
| 22C | 41.740 | 41.743 | 0.003 | 1 | OWP | 1.2 | 4 | Seal | | | No |
| | | | | | | TOTAL | 288 | 1.1% | of Area | | |
| | | | | | | | | 3.0% | of Wheelpaths | | |
| 22C | NOTE : Rut/shove failures consistently occur in adjacent (non-WCLT) section between 42.30 through to 47.0km | | | | | | | | | | |
| 22C | 47.080 | 49.400 | 2.32 | | SECTION 2 | 11 | 25,520 | Seal | Pavement Age : 21 Years | Full Width pavement | |
| 22C | 47.470 | 47.530 | [redacted] | 1,2 | Lane | 7 | 0 | Seal | OLD PATCH - not recorded as current failure | | No |
| 22C | 47.530 | 47.610 | [redacted] | 1,2 | Lane | 7 | 0 | Seal | OLD Failed areas FULL WIDTH - not current failure | | No |
| 22C | 47.610 | 47.670 | [redacted] | 1,2 | Lane | 7 | 0 | Seal | OLD PATCH - not recorded as current failure | | No |
| 22C | 47.670 | 47.740 | [redacted] | 1,2 | Lane | 7 | 0 | Seal | OLD Failed areas FULL WIDTH - not current failure | | No |
| 22C | 47.810 | 47.840 | 0.03 | 1 | OWP | 1.2 | 36 | Seal | Rut/Shove | | No |
| 22C | 48.110 | 48.130 | [redacted] | 1 | Lane | 3.5 | 0 | Seal | OLD PATCH - not recorded as current failure | | No |
| 22C | 48.240 | 48.650 | [redacted] | 1 | Lane | 3.5 | 0 | Seal | OLD PATCH - not recorded as current failure | | No |
| 22C | 48.740 | 48.750 | 0.01 | 1 | OWP | 1.2 | 12 | Seal | Rut/Shove ; 2x 5m apart | | No |
| 22C | 49.110 | 49.140 | [redacted] | 1 | LAne | 3.5 | 0 | Seal | OLD PATCH - not recorded as current failure | | No |
| 22C | 49.120 | 49.400 | Summit Section has been problematic for years (advice from TMR reps); many old and new patches, not recorded for this evaluation | | | | | | | | |
| 22C | | | 0 | | | TOTAL | 48 | 0.2% | of Area | | |
| 22C | | | 0 | | | | | 0.5% | of Wheelpaths | | |
| 22C | Many existing pavement repairs in this section - 21 year old pavement, possibly at the end of its life | | | | | | | | | | |
| 22C | 50.260 | 52.300 | 2.04 | | SECTION 3 | 11 | 22,440 | Seal | Pavement Age : 19 & 24 Years | Full Width pavement; Widen and Overlay | |
| 22C | 50.350 | 50.440 | [redacted] | 1,2 | Lane | 7 | 0 | Seal | OLD PATCH - not recorded as current failure | | No |
| 22C | 50.440 | 50.460 | 0.02 | 2 | Lane | 3.5 | 70 | Seal | | | No |
| 22C | 50.470 | 50.900 | [redacted] | 1,2 | Lane | 7 | 0 | Seal | OLD PATCH - not recorded as current failure | | No |
| 22C | 50.490 | 50.510 | 0.02 | 2 | OWP | 1.2 | 24 | Seal | Failure of old patch | | No |
| 22C | 50.530 | 50.532 | 0.002 | 2 | OWP | 1.2 | 2 | Seal | pothole | | No |
| 22C | 50.610 | 50.612 | 0.002 | 2 | OWP | 1.2 | 2 | Seal | rut/shove | | No |
| 22C | 50.950 | 50.960 | 0.01 | 2 | OWP | 1.2 | 12 | Seal | rut/shove | | No |
| 22C | 50.990 | 51.020 | 0.03 | 2 | OWP | 1.2 | 36 | Seal | rut/shove | | No |
| 22C | 51.050 | 51.060 | 0.01 | 1 | OWP | 1.2 | 12 | Seal | rut/shove | | No |
| 22C | 51.110 | 51.120 | 0.01 | 1 | OWP | 1.2 | 12 | Seal | rut/shove | | No |
| 22C | 51.200 | 51.210 | 0.01 | 2 | OWP | 1.2 | 12 | Seal | rut/shove | | No |
| 22C | 51.350 | 51.360 | 0.01 | 2 | OWP | 1.2 | 12 | Seal | rut/shove - overtaking lane | | No |
| 22C | 51.410 | 51.430 | 0.02 | 2 | OWP | 1.2 | 24 | Seal | rut/shove - overtaking lane | | No |
| 22C | 51.620 | 51.680 | [redacted] | 1 | Lane | 3.5 | 0 | Seal | OLD PATCH - not recorded as current failure | | No |
| 22C | 51.970 | Seal Change | [redacted] | | | | 0 | Seal | Seal Change / Pavement Change | | No |
| 22C | 52.160 | 52.162 | 0.002 | 1 | OWP | 1.2 | 2 | Seal | rut/shove | | No |
| 22C | 52.340 | 52.342 | 0.002 | 1 | OWP | 1.2 | 2 | Seal | rut/shove | | No |
| 22C | The adjacent non-WCLT section between 52.4 - 53.5 has 6 major patches of varying lengths | | | | | | | | | | |
| 22C | | | | | | TOTAL | 224 | 1.0% | of Area | | |
| 22C | | | | | | | | 2.7% | of Wheelpaths | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **22C** | **54.470** | **54.740** | 0.27 | | **SECTION 4** | **11** | **2,970** | Seal | **Pavement Age : 49 Years (??)** | **Full Width pavement** | |
| 22C | 54.610 | 54.613 | 0.003 | 1 | OWP | 1.2 | 4 | Seal | Rut/Shove | | No |
| 22C | McDonalds at 55.21km; a number of faliures and patches in this non-WCLT section | | | | | | | | | | |
| 22C | | | | | | TOTAL | 4 | 0.1% | of Area | | |
| 22C | | | | | | | | 0.3% | of Wheelpaths | | |
| **22C** | **63.480** | **65.240** | 1.76 | | **SECTION 5** | **12** | **21,120** | Seal | **Pavement Age : 29 Years** | **Full Width pavement** | |
| 22C | **NO FAILURES** | | | | | | 0 | Seal | | | No |
| 22C | **Overtaking lanes Southbound and Northbound - 4 Lanes for most of the length** | | | | | | | | | | No |
| 22C | | | | | | TOTAL | 0 | 0.0% | of Area | | |
| 22C | | | | | | | | 0.0% | of Wheelpaths | | |
| **22C** | **65.490** | **67.690** | 2.2 | | **SECTION 6** | **11** | **24,200** | Seal | **Pavement Age : 24 Years** | **Full Width pavement** | |
| 22C | 66.180 | 66.290 | 0.11 | 2 | OWP | 1.2 | 132 | Seal | Rut/Shove - in cutting (sub soil drainage?) | | No |
| 22C | 66.370 | 66.372 | 0.002 | 2 | OWP | 1.2 | 2 | Seal | Rut/Shove | | No |
| 22C | 66.560 | 66.580 | 0.02 | 2 | OWP | 1.2 | 24 | Seal | Rut/Shove | | No |
| 22C | 66.610 | 66.640 | 0.03 | 1 | OWP | 1.2 | 36 | Seal | Rut/Shove | | No |
| 22C | 66.610 | 66.630 | 0.02 | 2 | OWP | 1.2 | 24 | Seal | Rut/Shove | | No |
| 22C | 66.830 | 66.930 | 0.1 | 1 | OWP | 1.2 | 120 | Seal | Rut/Shove | | No |
| 22C | 67.070 | 67.075 | 0.005 | 1 | OWP | 1.2 | 6 | Seal | Rut/Shove | | No |
| 22C | 67.130 | 67.180 | 0.05 | 1 | OWP | 1.2 | 60 | Seal | Rut/Shove | | No |
| 22C | | | | | | TOTAL | 404 | 1.7% | of Area | | |
| 22C | | | | | | | | 4.6% | of Wheelpaths | | |
| **22C** | **73.560** | **75.640** | 2.08 | | **SECTION 7** | **14** | **29,120** | Seal | **Pavement Age : 27 Years** | **Full Width pavement** | |
| 22C | 73.660 | 73.690 | 0.03 | 1 | OWP | 1.2 | 36 | Seal | Rut/Shove | | No |
| 22C | 73.720 | 73.730 | 0.01 | 1 | OWP | 1.2 | 12 | Seal | Rut/Shove | | No |
| 22C | 73.990 | 74.010 | 0.02 | 2 | OWP | 1.2 | 24 | Seal | Rut/Shove | | No |
| 22C | 74.340 | 74.360 | 0.02 | 1 | OWP | 1.2 | 24 | Seal | Rut/Shove | | No |
| 22C | 74.820 | 74.990 | 0.17 | 2 | OWP | 1.2 | 204 | Seal | Rut/Shove | | No |
| 22C | 74.920 | 74.940 | 0.02 | 1 | OWP | 1.2 | 24 | Seal | Rut/Shove | | No |
| 22C | NOTE : Overtaking lanes Southbound 73.56 - 74.42; then swaps to Northbound OT lane (3 Lanes wide for most of the project) | | | | | | | | | | |
| 22C | | | | | | TOTAL | 324 | 1.1% | of Area | | |
| 22C | | | | | | | | 3.9% | of Wheelpaths | | |
| **22C** | **87.010** | **91.600** | 4.59 | | **SECTION 8** | **12** | **55,080** | Seal | **Pavement Age : 37 Years** | **Full Width pavement** | |
| 22C | 87.450 | 87.470 | 0.02 | 1 | OWP | 1.2 | 24 | Seal | Rut/Shove | | YES |
| 22C | 88.440 | 88.460 | 0.02 | 1 | Lane | 3.5 | 70 | Seal | Rut/Shove | | YES |
| 22C | 88.870 | | [redacted] | 1,2 | Lane | 3.5 | 0 | Seal | **OLD PATCH - not recorded as current failure; 3 x 60-70m patche** | | YES |
| 22C | 88.830 | 88.930 | 0.1 | 1,2 | Lane | 7 | 700 | Seal | Rutting | | YES |
| 22C | 90.500 | 90.520 | 0.02 | 1,2 | Lane | 7 | 140 | Seal | Rut/Shove | | YES |
| 22C | 91.580 | 91.600 | 0.02 | 1 | OWP | 1.2 | 24 | Seal | Rut/Shove | | YES |
| 22C | Note : Overtaking Lane Southbound 87.01 - 87.92 | | | | | | | | | | |
| 22C | | | | | | TOTAL | 958 | 1.7% | of Area | | |
| 22C | | | | | | | | 5.2% | of Wheelpaths | | |
| | **TOTAL** | | **17.67** | | | | | | | | |
| | **Total Area of Pavement** | | **206,960** | | | | | | | | |
| | **Total Area of Failure** | | **2,250** | *1.1%* | | | | | | | |
| | **Failures as % of Wheelpaths** | | | *3.2%* | | | | | | | |

22C 39.88 a

22C 39.88 b

22C 39.88 c

22C 39.88 d

22C 39.91 a

22C 40.49 a

22C 40.49 b

22C 41.03 a

22C 41.03 b

22C 41.47 a

22C 41.47 b

22C 41.47 c


22C 41.47 d


22C 41.72 a


22C 41.72 b


22C 47.09 a


22C 47.09 b


22C 47.98 a


22C 47.98 b


22C 47.98 c


22C 47.98 d


22C 47.98 e


22C 50.44 a


22C 50.44 b

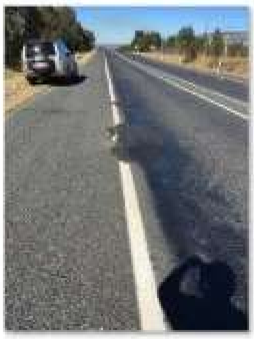

22C 50.44 c


22C 50.44 d


22C 50.44 e


22C 50.44 f


22C 50.44 g


22C 51.13 a


22C 51.13 b

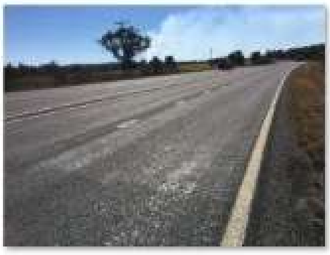

22C 51.13 c


22C 51.36 a


22C 51.36 b


22C 51.36 c


22C 64.41 a


22C 64.41 b


22C 64.41 c


22C 64.41 d


22C 64.41 e


22C 64.41 f


22C 64.41 g

22C 66.30 a

22C 66.30 b

22C 66.30 c

22C 66.30 d

22C 66.30 e

22C 66.30 f

22C 66.30 g

22C 66.83 a

22C 66.83 b


22C 66.83 c


22C 74.42 a


22C 74.42 b


22C 74.42 c


22C 74.42 d


22C 74.95 a


22C 74.95 b


22C 74.95 c


22C 74.95 d


22C 74.95 e


22C 88.34 a


22C 88.34 b


22C 88.34 c


22C 88.34 d


22C 88.34 e

22C 91.65 a

22C 91.65 b

22C 91.65 c

22C 91.65 d

22C 91.65 e

# APPENDIX E CQU IMAGE ANALYSIS REPORT

# Project Report

| Project Details | |
|---|---|
| Organization | Central Queensland University – Centre for Intelligent Systems |
| Project Name/ Description | WCLT Image Processing |
| Client | ARRB Group |
| Project Number | PRP16038 |
| Survey Location | Warwick and Mackay |
| **Report Author** | |
| Name | Brijesh Verma |
| Position | Professor & Director |
| Signature | |
| Date | |

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# 1. Summary

This report presents an image processing technique for automatically finding the impact of Wide Centre Line Treatment (WCLT). The proposed technique can measure distances and vehicle lengths to find the impact of WCLT on the pavement. The extensive experiments have been conducted on two sites (near Warwick and Mackay) to analyze the impact of the treatment. Data have been collected using two video cameras simultaneously for single and wide centre lines. Figures 1 and 2 show sample images collected from both single line and WCLT.


Fig. 1. The Single Line Detail from Mackay Site

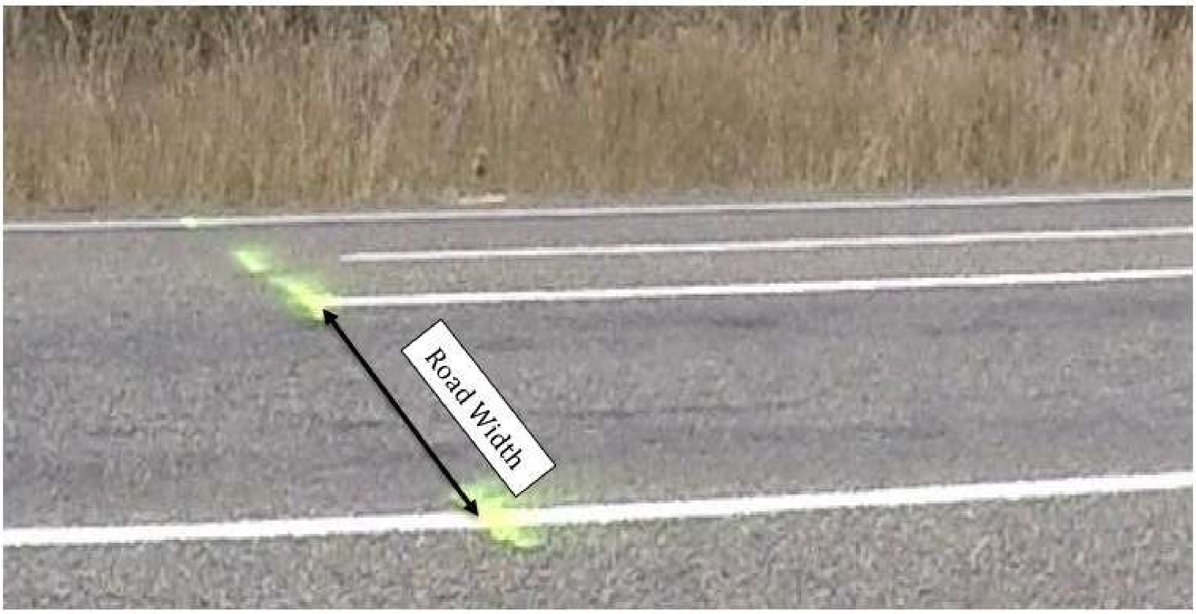


Fig. 2. The Wide Centre Line Treatment (WCLT) Detail from Mackay Site

## 2. RESEARCH QUESTIONS

The proposed image processing technique seeks to answer the following questions.

- Does the WCLT treatment cause the heavy vehicle to drive closer to the centreline or closer to the shoulder line, in an absolute sense and in comparison to sections without WCLT?
- Does the WCLT treatment lead to channelization of heavy vehicles and reduced vehicle wander?

## 3. PROPOSED TECHNIQUE

The proposed framework is presented in this section. Figure 3 shows the geometric model for our target area. A sketch of the vehicle shows the movement of the vehicle. The captured images in this research were taken by a video camera.

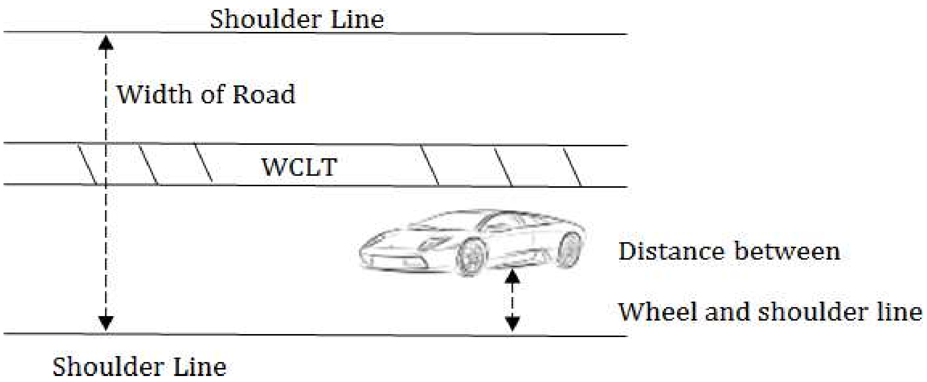



Fig. 3. Geometrical Street Model Encompassing Vehicle and Shoulder Line

Figure 4 shows the basic block diagram of our proposed geometric distance calculation model. Initially, proposed method converts the RGB image into gray scale image and extracts the road region. Later based on frame difference the vehicle region is extracted. Finally, a target point method extracts the overlap pixel regions and calculates the distance.

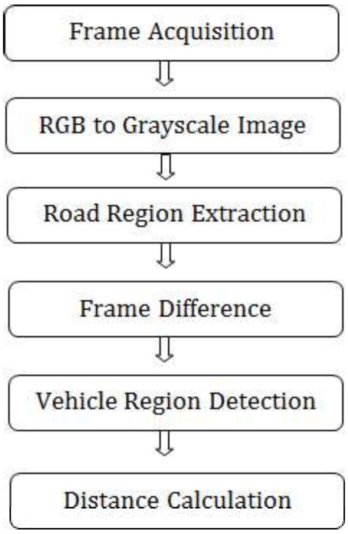



Fig. 4. Proposed Geometrical Distance Calculation Model

### 3.1 Frame Acquisition

The extraction of frames from the video is one of the first and most important tasks for image analysis. A frame with a good resolution and a viewpoint can give proper information about the real scenario. After extracting the frames, the next task is to calculate the distance and length. The whole process will fail if proposed data collection cannot collect appropriate frames. If frames cannot be collected properly, it will be impossible to extract desired information using even advance image processing techniques. To capture appropriate images and long-term maintenance, the initial setup is important. If the setup is not properly configured, the acquired image task will become complicated. Sometimes due to improper hardware setup, low-quality images are provided which cannot be processed accurately. In this research, we collected data from properly installed video cameras which provide a clear view of the road. We got very good image resolution as shown in Figure 5. The acquired image has the resolution 1920 x 1080.

Fig. 5. Road Details

Figures 6 and 7 below show some examples of camera setup in the surveyed locations.

Fig. 6. Camera Setup (Nikon)

Fig. 7. Camera Setup (GoPro)

## 3.2 Scale Conversion

The grayscale image represents the intensity of the image. The intensity information is important to extract appropriate information from the image.

## 3.3 Road Region Extraction

Extracting the road region from the acquired image frames is one of the most important tasks for analyzing roadside condition. As proposed method is using the static cameras, the task is easier in comparison to moving cameras. The road surrounding and conditions may change because of the wind, weather, etc. To avoid the impact of the wind and other environmental factors, we analyze the roadside region and extract the road from the pixel information.

### 3.4 Frame Difference Calculation

One of the critical challenges of the proposed analysis is to find the change on two different frames. Depending on the change we need to count the number of vehicles, length of the vehicle and calculate the distance between the shoulder line and the vehicle. As proposed method calculates the length of the vehicle and distance from shoulder line in respect to a single vehicle, there should be no overlapping within the vehicle region. If the target vehicle overlapped with other vehicle or blocked by something else, the information will not be correct. The change may happen due to the wind or other environmental factors. So the task is challenging. To overcome the challenges, the proposed method focuses only on changes on road rather than detection of whole environmental change. Initially, we take the first frame as a standard frame and keep tracking the change on the road. If any change on the road, we analyze whether it is due to the vehicle or any abrupt change. We check the length, shape, and type of change on the road. As our focus is only on the road, we ignore the other change in the entire image. As we are focusing only on road it makes the task easier to trace the change. We keep tracking the frame until we reach the end of the vehicle and get the frame similar to an original frame.

### 3.5 Vehicle Region Detection

Detecting vehicle region and calculation of the length is the main challenge of this work. The task is easy if the whole frame contains the vehicle. Figure 8 shows a frame with whole vehicle region covered within the frame while Figure 9 shows that the whole vehicle is not visible within one frame. That's why we need to keep track of the entire frame until the whole vehicle region is covered. The distance is calculated based on the whole frame sequence. From the frame, we can only count the number of pixels that is covered by the vehicle. To calculate the actual length of the vehicle we use spatial pixel information and finally calculate the actual length in meters. The calculation for length is different for the different video cameras. As this is based on the position information and based on the viewpoint, we assign different values for different cameras. The general equation used to calculate the number of pixels that belong to the vehicle is given below:

$$Length\ of\ vehicle = (Total\ no.\ of\ vehicle\ pixel * R)$$

Where

$$R = \frac{Actual\ Vehicle\ width}{no. of\ coverage\ pixel}$$

Fig. 8. Vehicle Covered within One Frame

Fig. 9. Vehicle not Visible within One Frame

As mentioned earlier and shown in Figure 10, while calculating the total number of vehicle pixels we keep adding the number of the pixels from the different frames.

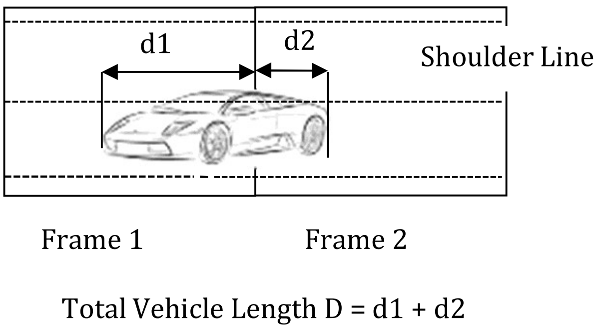



Fig. 10. Vehicle Length Calculation

Algorithm 1 shows the steps of vehicle length calculation from the frame sequence. Median filtering was applied on grayscale image to make the image smooth. To make the binary image, an automatic thresholding technique was used. To detect the actual region morphological operation was conducted using designed structure element. In order to remove the noise, we find out the connected component and used the information to define the whole vehicle region. We choose the biggest component to define the vehicle region. Later we calculate the bounding box to detect the vehicle length. This length doesn't give us the actual vehicle length so as shown in Figure 11 we need to check the next frame sequence and by similar technique need to find out the vehicle region and keep adding to the previous length.


Total Vehicle Length D = d1 + d2

Fig. 11. Vehicle Length Calculation (From real image)

---

*Algorithm 1: Vehicle Length Calculation*

---

***Input**: $Z_2$ is the input and $V$ is the processed image for Length calculation.*

```
Filter_image = rgb2gray(Z2); Filter_image = medfilt2(Filter_image);

level = graythresh(Filter_image); BW_new = im2bw(Z2,level);

se = strel('disk',4); BW_new = imclose(BW_new,se);

[Rs,Cs]=size(BW_new);

V = zeros(Rs,Cs);

CC = bwconncomp(BW_new);

numPixels = cellfun(@numel,CC.PixelIdxList);

[biggest,idx] = max(numPixels);

V(CC.PixelIdxList{idx}) = 1;
```

---

```
stats = regionprops(V,'BoundingBox');
corner_x = floor(stats.BoundingBox(1));
corner_y = floor(stats.BoundingBox(2));
width = floor(stats.BoundingBox(3));
height = floor(stats.BoundingBox(4));
stat = regionprops(V,'Centroid');
xc = stat(1).Centroid(2);
yc = stat(1).Centroid(1);
car_position = [yc xc];
car_length = width;
```

$$Final\ Length = \mathbf{L}\ width$$

***Output:*** *Vehicle length in meter*

## 3.6 Distance Calculation

In order to calculate the distance from shoulder line to the wheel position, we move the shoulder line upward towards wheel position and calculate the number of overlapping pixels. Based on the overlapping pixels we decide whether we reached to the wheel position or not. Then we calculate the pixel difference between the overlapped region and standard shoulder line pixels. Based on the width of the road we convert the distance into standard scale. Figures 12 and 13 show some examples for distance calculation.

*Algorithm 2: Distance Calculation*

***Input***: *$L_1$ be the shoulder line and $V_1$ be the vehicle position in the image.*

*1:* ***procedure*** *DistanceCalc*

*2: input: Captured Frame $P$ € $C^{M \times N}$*

*2: Initialization*

*base_shoulder_line ⊠(row_pos, col_pos),*

*distance ⊠ 0;*

*3:* ***begin***

*4:* ***While 1***

*5:* ***do***

*6: Extract new line $L_i$*

*7: Calculate overlapped pixel on $V_1$*

*8:* ***if*** *length> threshold*

*9:* ***break****;*

*10:* ***end***

*11: new_line ⊠ (row_pos -1, col_pos)*

*12: i = i + 1;*

*13:* ***end***

*14: final_distance⊠ base_shoulder_line – new_line*

***Output:*** *Distance between wheel and shoulder line*

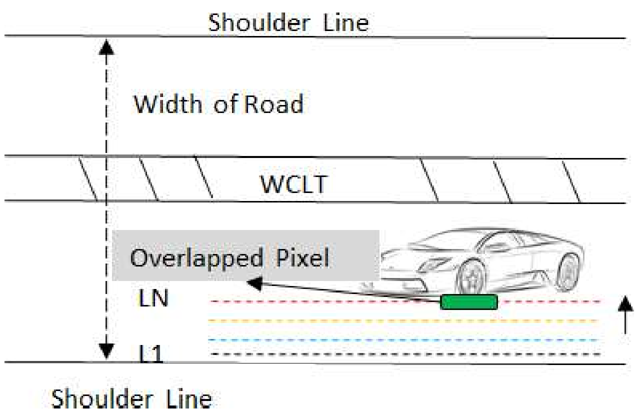



Fig. 12. Distance Calculation Process


Fig. 13. Distance Calculation from Shoulder line to Wheel

## 4. EXPERIMENTAL SETUP

The experiments are conducted using the data collected from Mackay and Warwick with the proposed methodology. The obtained results are analyzed to answer the research questions. We apply the proposed approach to analyze those images and count the number of heavy vehicles and calculate the transverse distance. We show some analysis of the results obtained using our proposed approach on two sites (Warwick and Mackay). We put the camera on the side of the road in such a way that, it is not usually visible to drivers from far considering the fact that driving behavior may change. We set one camera in the single line region and another camera in the WCLT region.

## 5. EXPERIMENTAL ANALYSIS

To validate the proposed method, two locations were selected from different parts of Queensland. The initial experiment was conducted near Warwick where two sites were chosen for a single line and WCLT that are only a few kilometer apart. We tracked the behavior of the same vehicle on both sites. After successful analysis, we tested the method in Mackay region using four sites. From the analysis shown below, we found that while there was a single line on the road, most of the drivers drive on the left side of the road within the range 10-40 cm. On the other hand, as soon as WCLT began the behavior changed and most of the drivers drive closer to the WCLT rather than the left side of the road and the range changed to 40-60 cm from the shoulder line. In next two sections we describe the survey results from Warwick and Mackay sites. Road information as well as pixel information is also presented. We also include the location information where survey was conducted.

### *5.1 Warwick Survey Report*

Total Heavy Vehicles: 160

1 Pixel = 1.79 cm (WCLT)

1 Pixel = 2 cm (Single Line)

We did the survey on September 28, 2016 from 10 am to 4 pm.


Fig. 14. Information about Road on WCLT


Fig. 15. Information about Road on Single Line

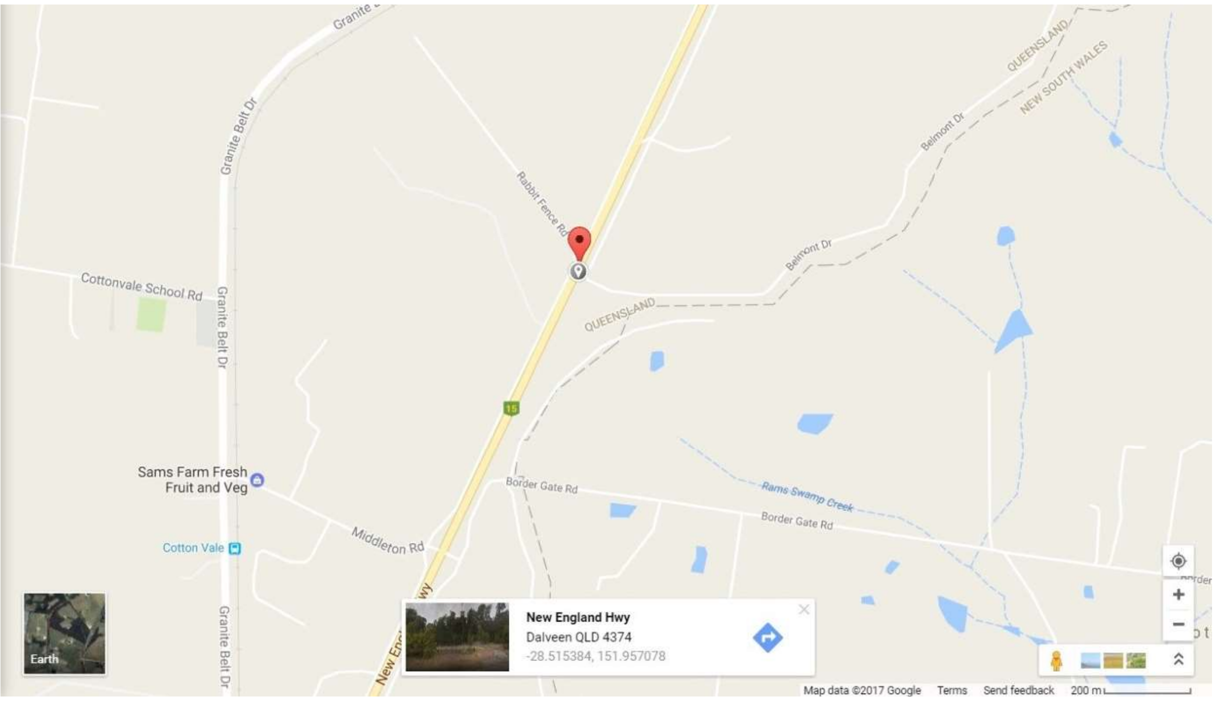



Fig. 16. GPS Coordinate for Warwick Survey Site 1

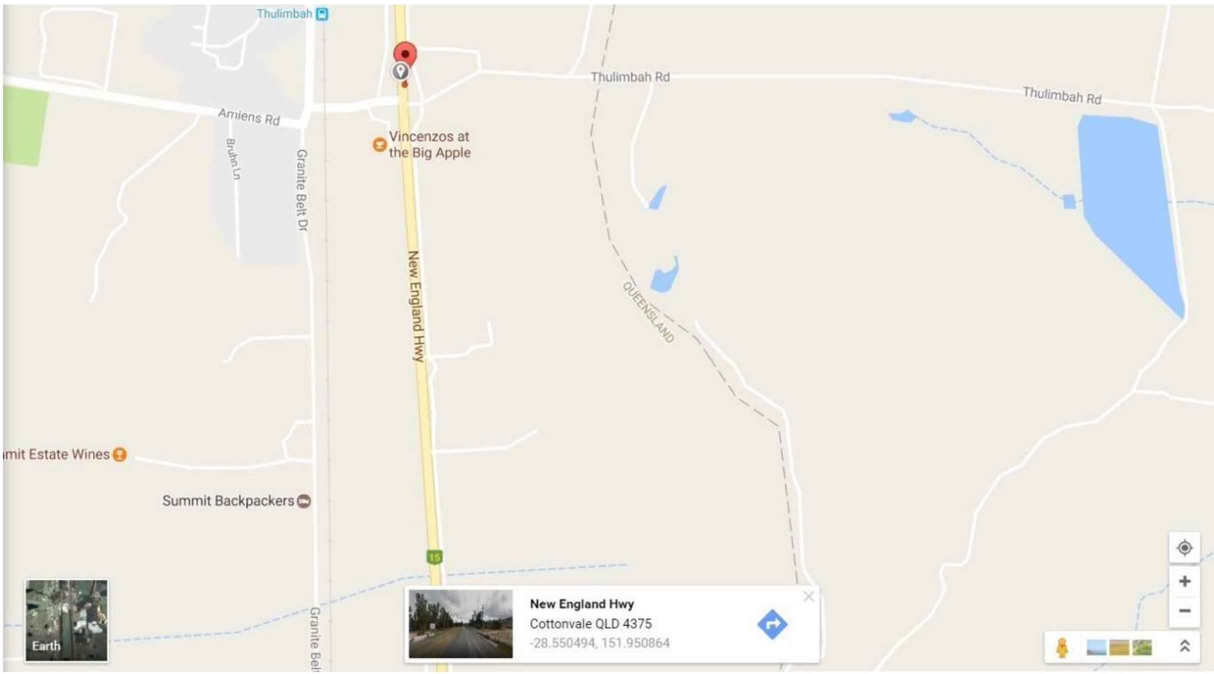



Fig. 17. GPS Coordinate for Warwick Survey Site 2

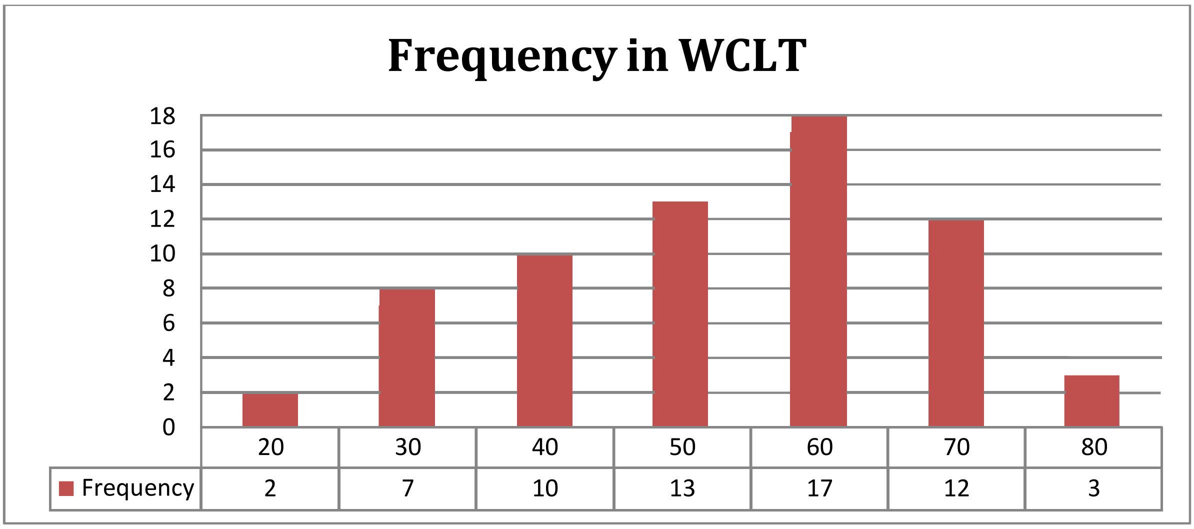



Fig. 18. Frequency on WCLT within different range of distance

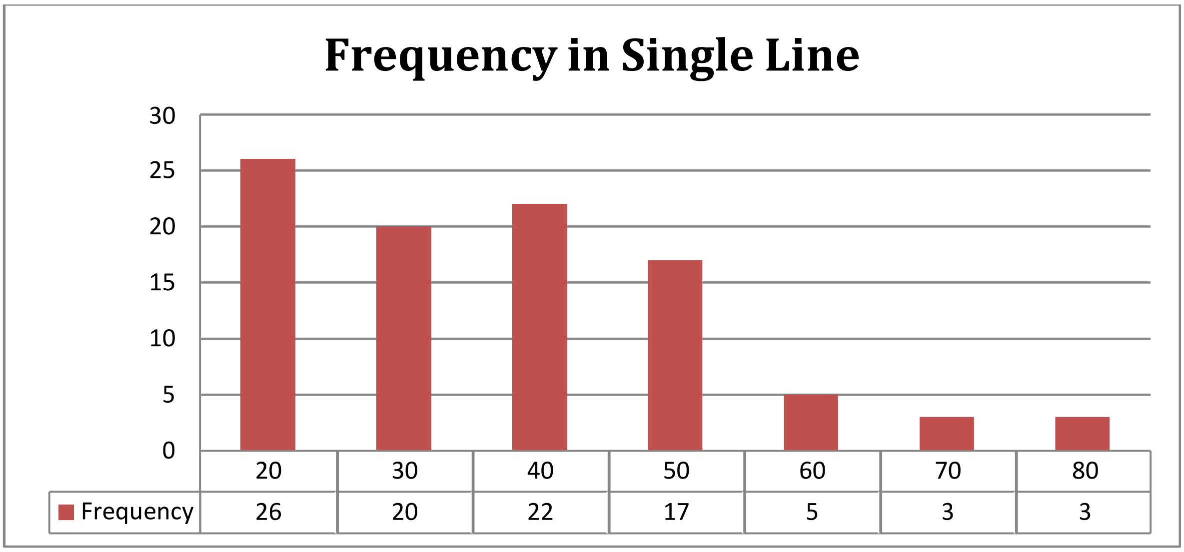



Fig. 19. Frequency on single line within different range of distance

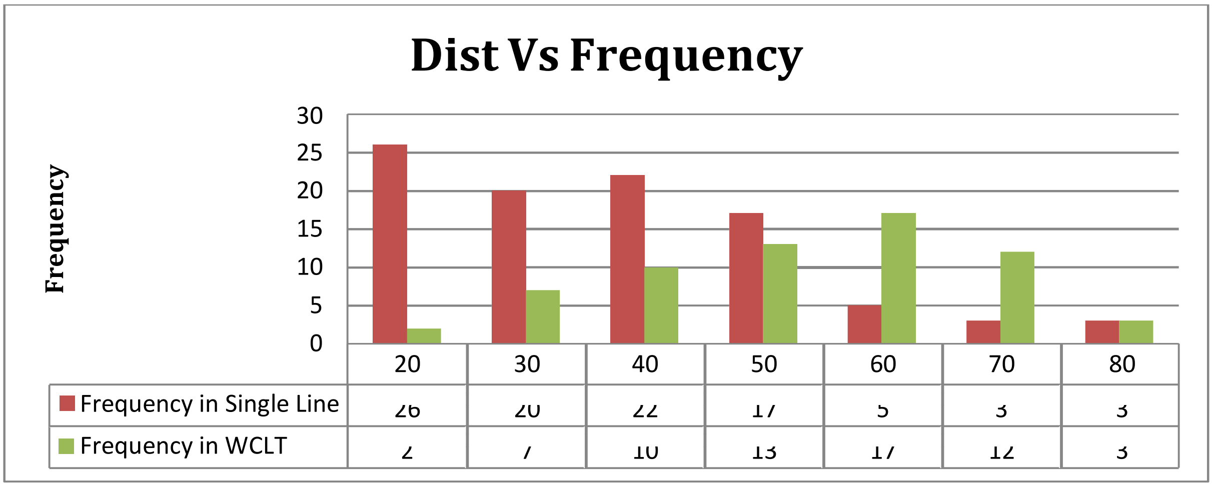



Fig. 20. Comparative analysis of driving behavior on both single line and WCLT within different range of distance

### 5.2 *Driving Behaviour - Single Line vs WCLT (Warwick Site)*

Figures 21 to 24 show some examples of driving behaviour in Warwick sites. From the images, it is clear that, while there is WCLT, drivers feel more comfortable on driving closer to WCLT, while in the case of single line drivers mostly drive closer to the shoulder line. Although, the behaviour is not obvious for all drivers, there are some cases where driving behaviour changes. But our overall observation and collected samples show that, in most of the cases, driver behaviour follows the first scenario.


Fig. 21. Driver Behaviour on WCLT (Distance from Shoulder = 50.6 cm)


Fig. 22. Driver Behaviour on Single Line (Distance from Shoulder = 20.4 cm)


Fig. 23. Driver Behaviour on Single Line (Distance from Shoulder = 2 cm)

Fig. 24. Driver Behaviour on WCLT (Distance from Shoulder = 32.4 cm)

### *5.3 Mackay Survey Report*

There were four sites in Mackay; the pixel information varies across the sites due to different cameras setup. The survey was undertaken on three consecutive days from 10 am to 4 pm. The dates of data collection were November 15, 2016 to November 17, 2016.


Fig. 25. Car and Roadside Information for Site 1


Fig. 26. Roadside Conditions for Site 1

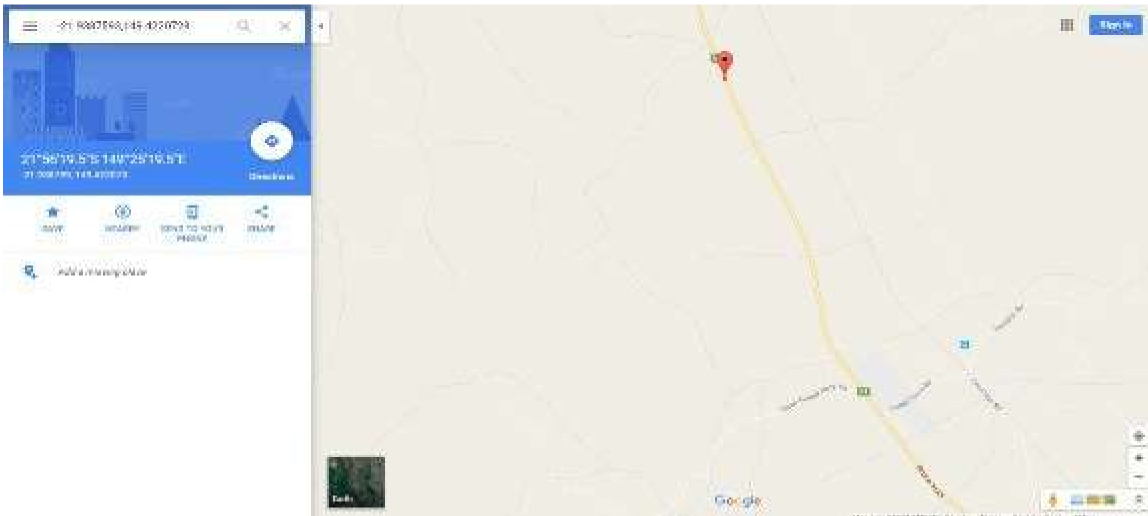


Fig. 27. Location Information based on GPS Coordinate for Site 1

TABLE I. SURVEY INFORMATION FOR SITE 1

| Type | Information |
|---|---|
| Survey | 10G_1 |
| Chainage | 53.749 km |
| Sub Chainage | 3.531 km |
| Location | Lat: -21.9387593 Lon: 149.4220728 Alt: 29.6 |
| Road Name: | S.ABUT/ FLAGGY ROCK C |
| From | 8 10G-8 |
| To | 9 10G-9 |


Our Car on Site 2 (WCLT)

Car length: 390 cm

1 pixel = 0.43 cm

Road Information

Road Width: 291 cm

1 pixel =2.7804 cm

Fig. 28. Car and Roadside Information for Site 2

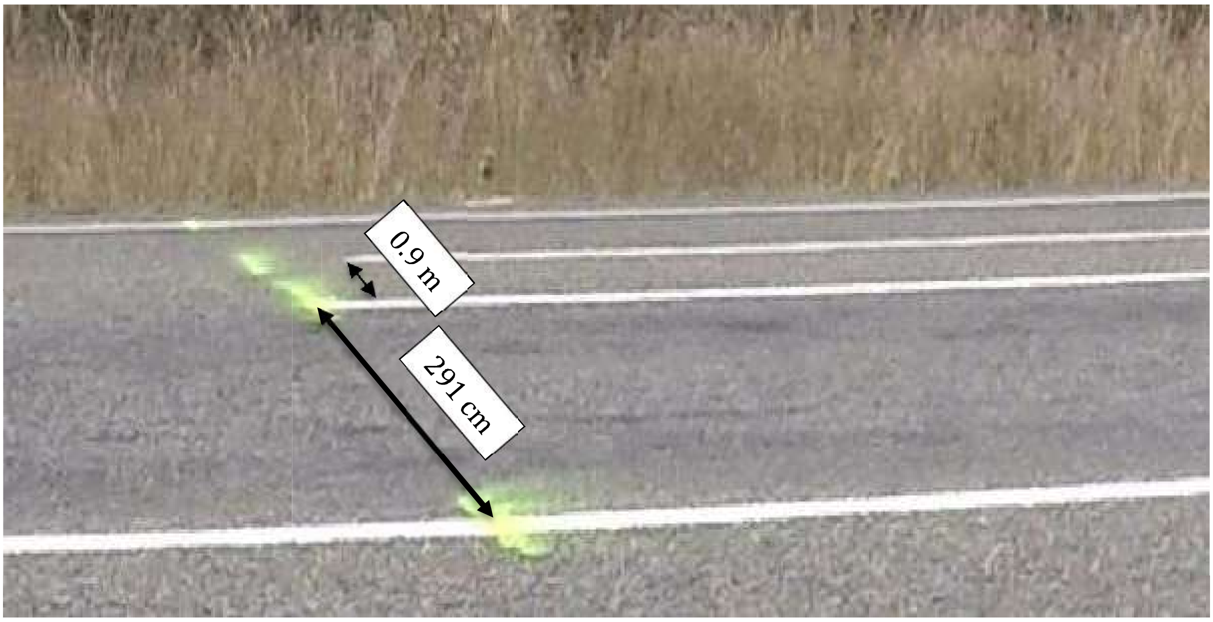



Fig. 29. Roadside Conditions for Site 2

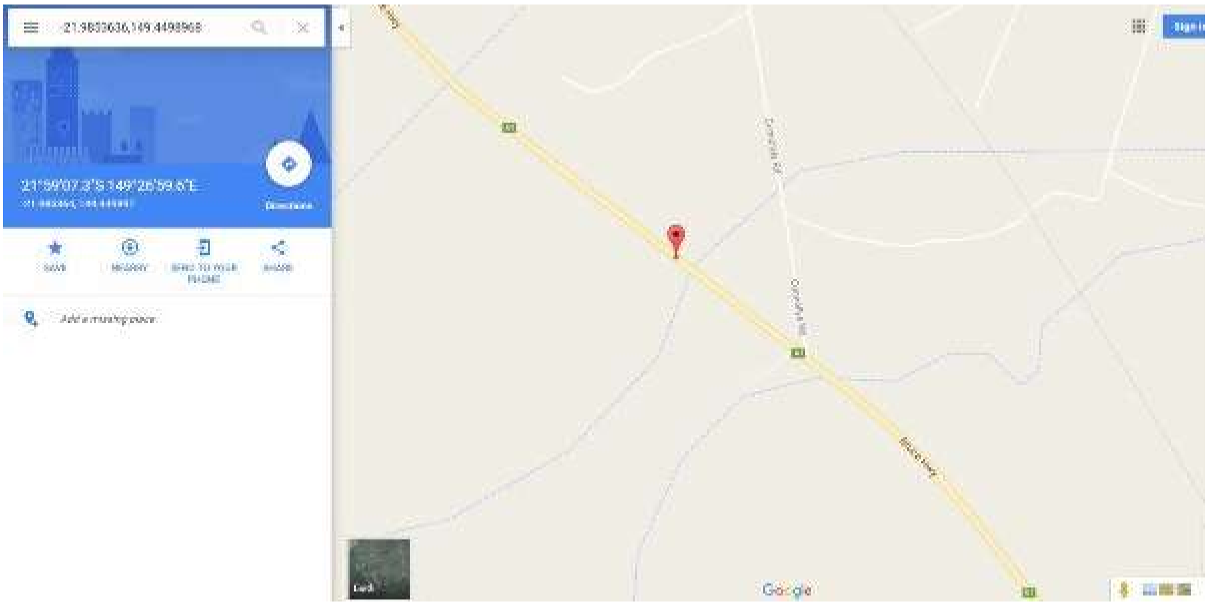


Fig. 30. Location Information based on GPS Coordinate for Site 2

TABLE II. SURVEY INFORMATION FOR SITE 2

| Type | Information |
|---|---|
| Survey | 10G_1 |
| Chainage | 47.699 km |
| Sub Chainage | 6.772 km |
| Location | Lat: -21.9853636 Lon: 149.4498968 Alt: 22.9 |
| Road Name: | S.ABUT/ OAKEY CK |
| From | 7 10G-7 |
| To | 8 10G-8 |


Fig. 31. Car and Roadside Information for Site 3


Fig. 32. Roadside Conditions for Site 3

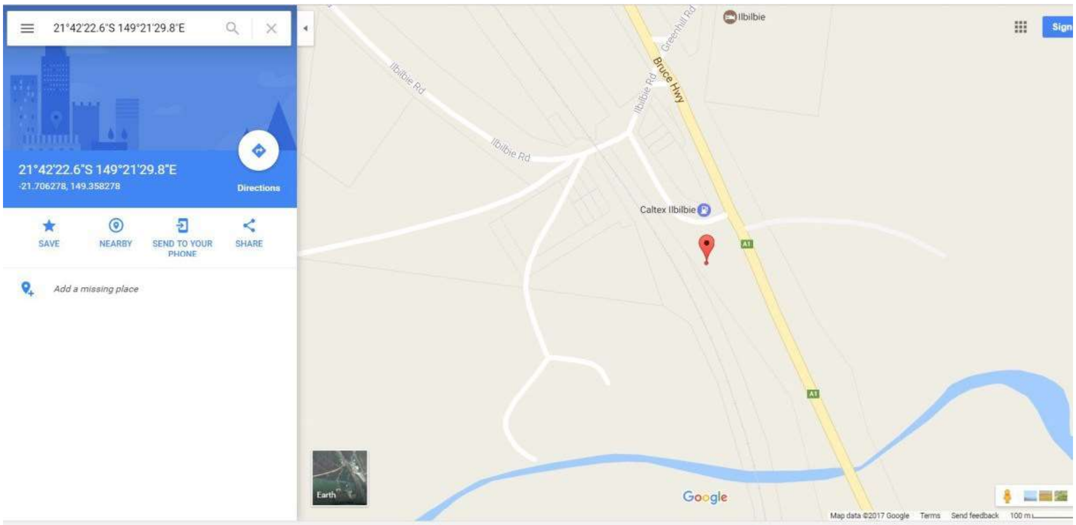
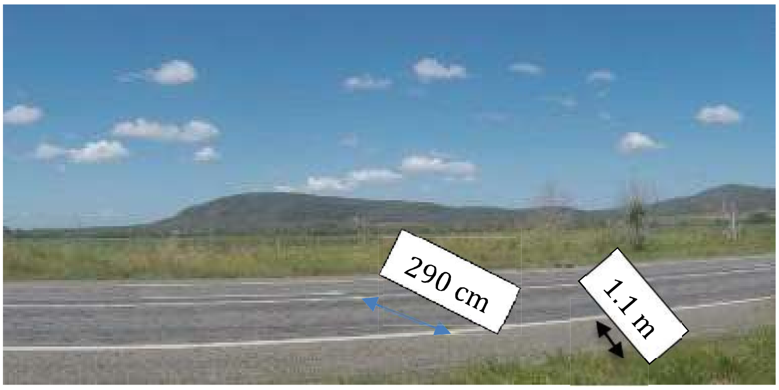



Fig. 33. Location Information based on GPS coordinate for Site 3

TABLE III. SURVEY INFORMATION FOR SITE 3

| Type | Information |
|---|---|
| Survey | 10G_15 |
| Chainage | 82.14 km |
| Location | Lat: -21.707333 Lon: 149.359510 |
| Road Name: | MARON CK |
| From | 15 10G-15 |
| To | 16 10G-16 |




Road Width: 290 cm

1 pixel = 2.19 cm

Fig. 34. Roadside Conditions for Site 4

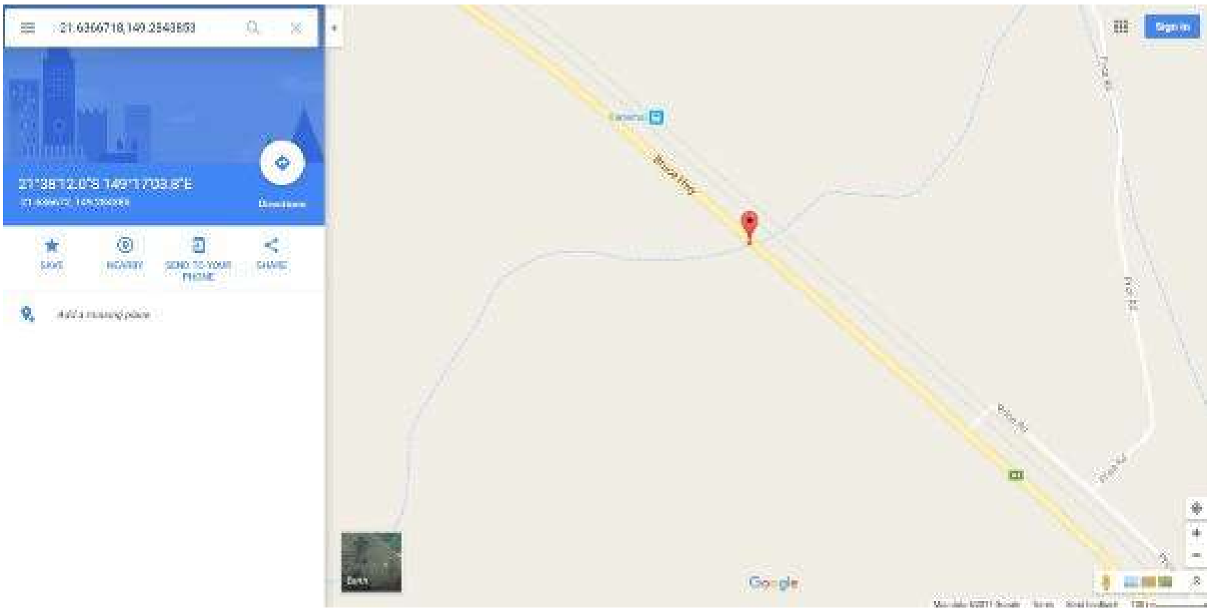



Fig. 35. Location Information based on GPS coordinate for Site 4

TABLE IV. SURVEY INFORMATION FOR SITE 4

| Type | Information |
|---|---|
| Survey | 10G_1 |
| Chainage | 93.769 km |
| Sub Chainage | 3.675 km |
| Location | Lat: -21.6366715 Lon: 149.2843853 Alt: 34.8 |
| Road Name: | S.ABUT/ROCKY DAM CK |
| From | 14 10G-14 |
| To | 15 10G-15 |

Total number of heavy vehicles: 268 (Single line: 161, WCLT: 107)

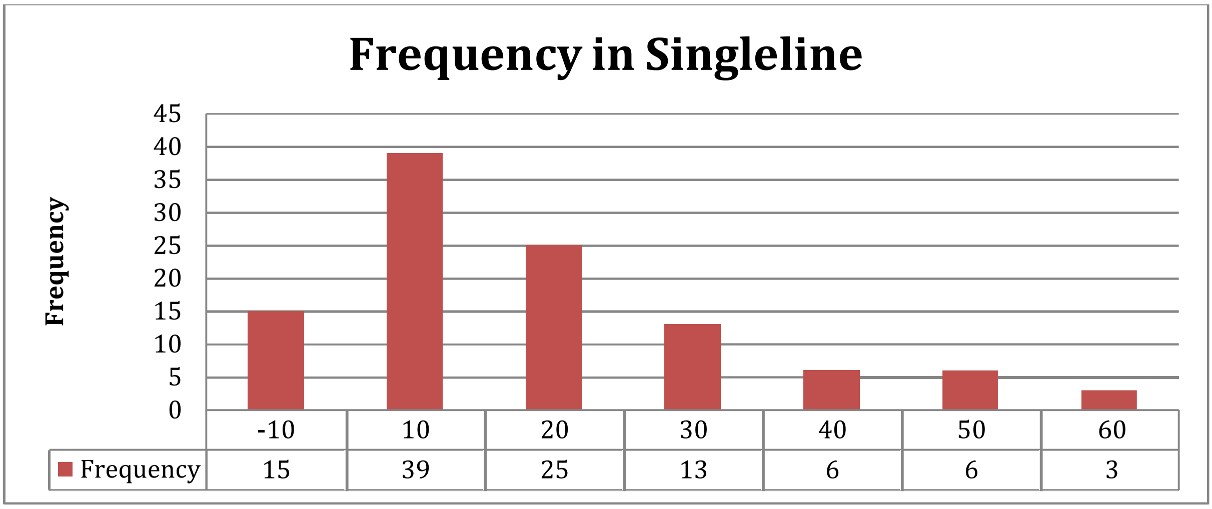



Fig. 36. Frequency on single line within different range of distance

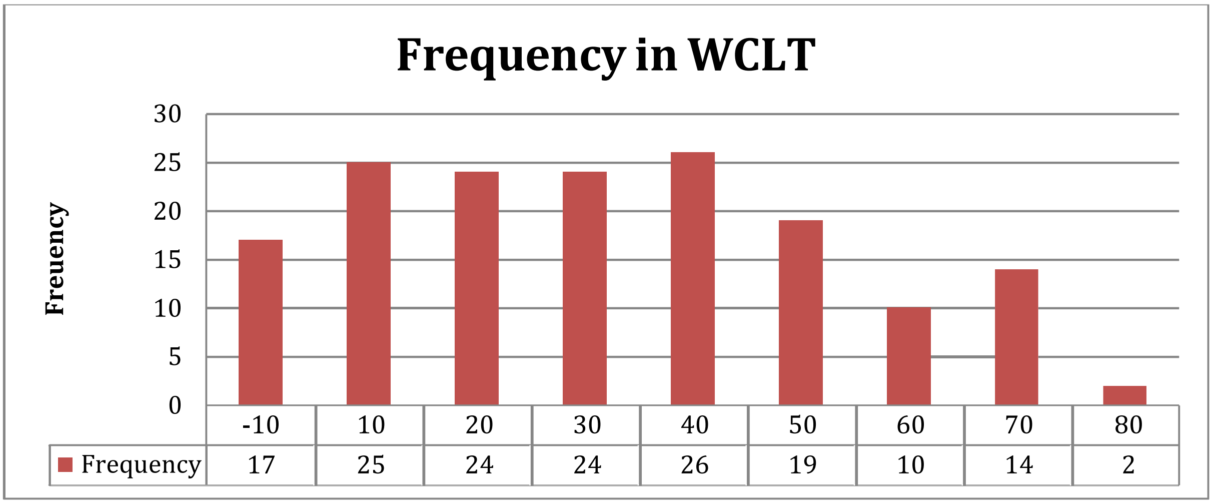



Fig. 37. Frequency on WCLT within different range of distance

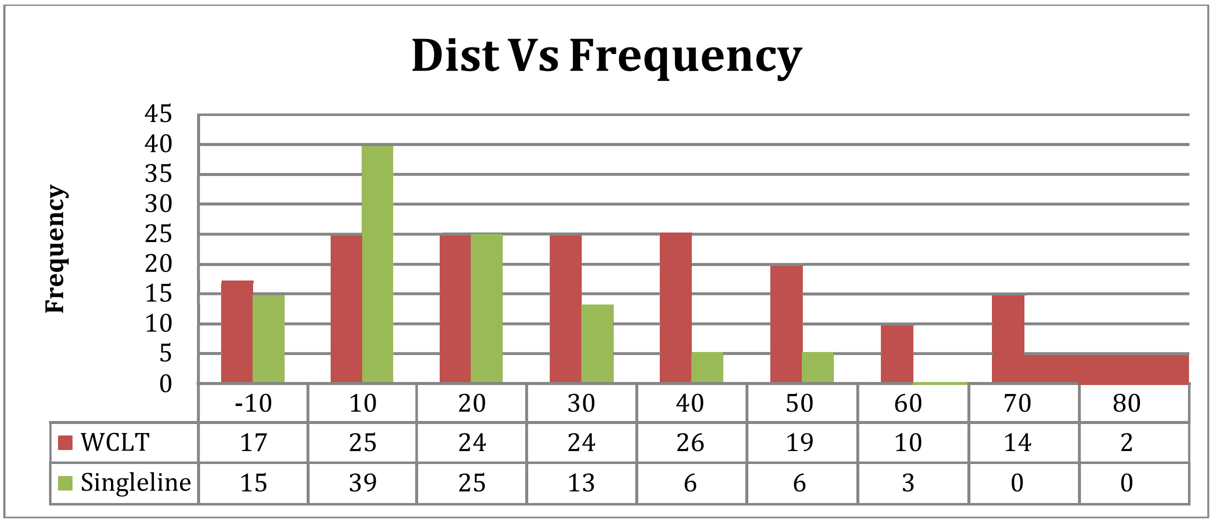



Fig. 38. Comparative analysis of driving behaviour on both single line and WCLT within different range of distance

### *5.4 Driving Behaviour- Single Line vs WCLT (Mackay Site)*

Fig. 39. Driver Behaviour on Single Line

Fig. 40. Driver Behaviour on WCLT


Fig. 41. Driver Behaviour on Single line


Fig. 42. Driver Behaviour on WCLT

## 6. SUMMARY OF RESULTS

Total number of vehicles: 2263 (953 vehicles in Warwick and 1310 vehicles in McKay)

Total number of Heavy Vehicles (HV): 428

Mackay (HV): 268

Warwick (HV): 160

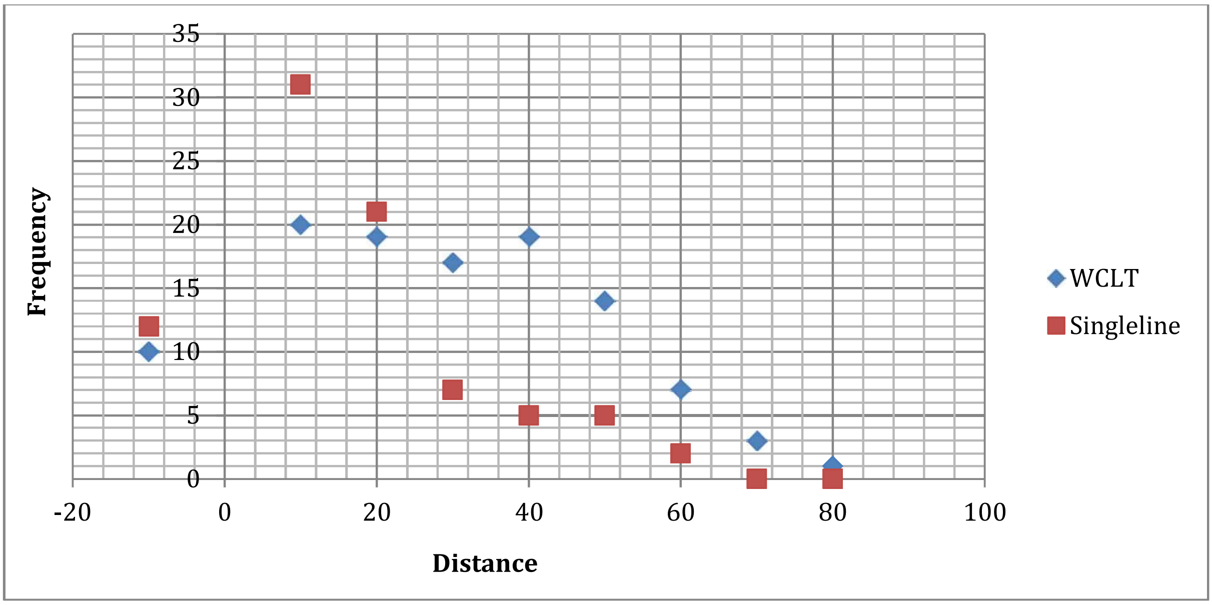



Fig. 43. Driving Behaviour on Site 1(Single Line and WCLT) Mackay Survey

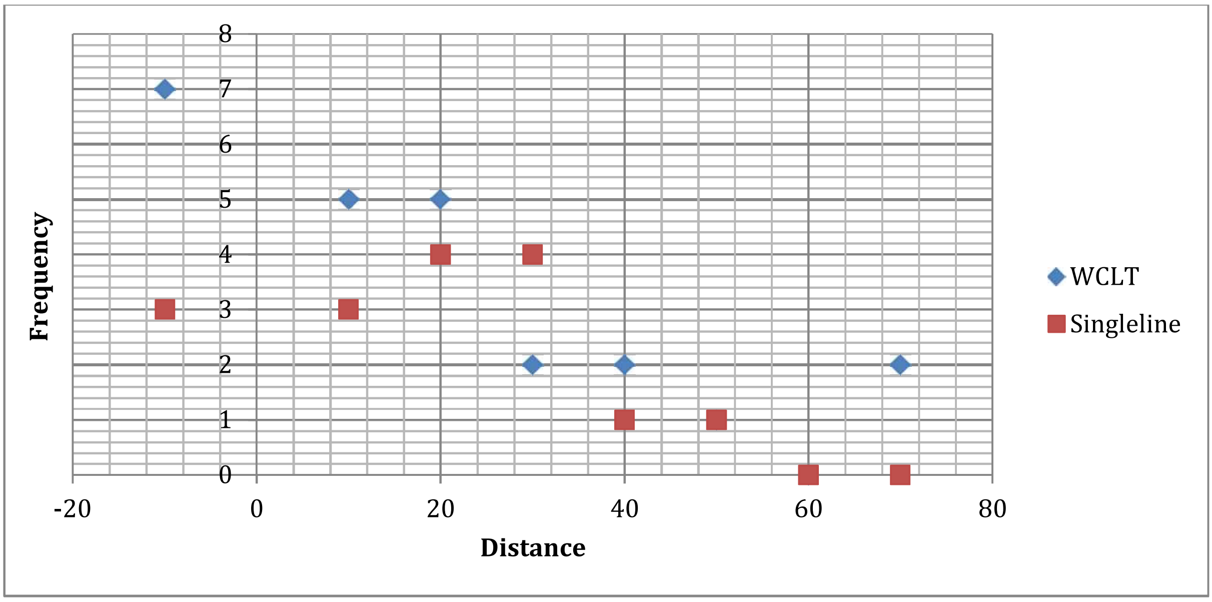



Fig. 44. Driving Behaviour on Site 2(Single Line and WCLT) Mackay Survey

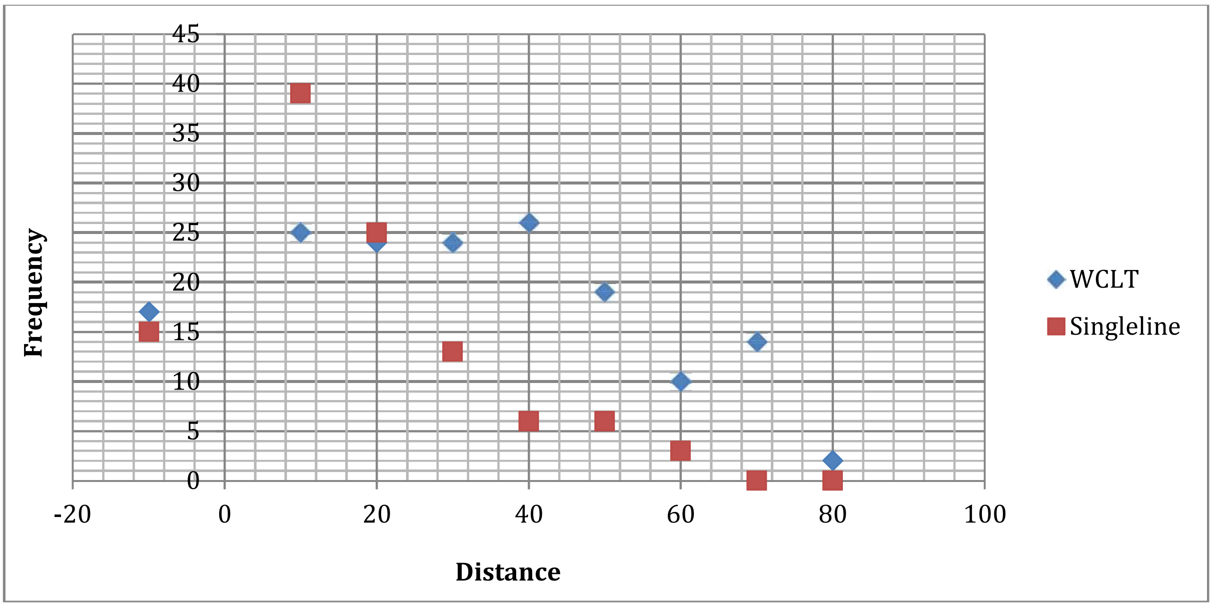



Fig. 45. Overall Driving Behaviour during Mackay Survey

From the above figure, it is clear that distances have a great impact on overall driving behaviour. We plotted the frequency of vehicles with respect to distance for both WCLT and single line. The blue diamond shape represents WCLT and red square shape represents single line. From the figure, it is clear that most of the vehicles driving within 30-60 cm while there is WCLT and most of the vehicles driving within 20 cm while there is single line. Same kind of scenario was found during Warwick survey which is shown in Figure 46.

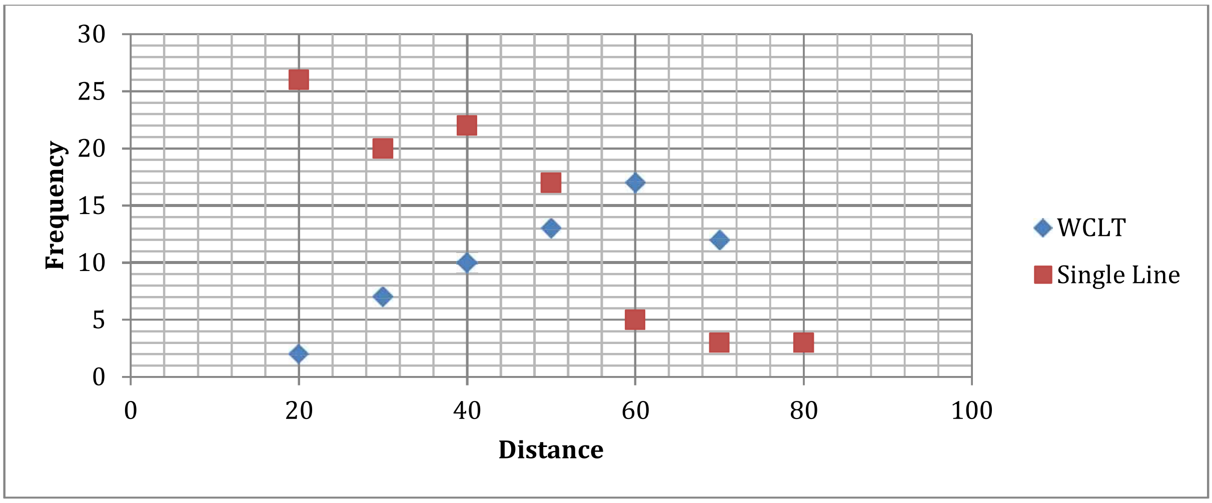



Fig. 46. Overall Driving Behaviour during Warwick Survey

## 7. SIGNIFICANCE TEST

To conduct a significance test, we set the null hypothesis as follows.

> There is a significant difference between the driving behaviour in WCLT region and single line region (H0: $\mu 1 - \mu 2 = 0$).

We conduct a two-tail test (inequality) on our processed data. In the case of the t-test, if t Stat < -t Critical two-tail or t Stat > t Critical two-tail, we reject the null hypothesis. In this case, we found the value -2.16 < 1.18 < 2.16 so, we don't reject the null hypothesis.

Therefore, we can say that the driving behaviour differs significantly between WCLT and single line.

TABLE V. T-TEST RESULT

t-Test: Two-Sample Assuming Unequal Variances

| | *WCLT* | *Single line* |
|---|---|---|
| Mean | 17.89 | 11.89 |
| Variance | 65.36 | 168.61 |
| Observations | 9 | 9 |
| Hypothesized Mean Difference | 0 | |
| Df | 13 | |
| t Stat | 1.17677 | |
| P(T<=t) one-tail | 0.13019 | |
| t Critical one-tail | 1.77093 | |
| P(T<=t) two-tail | 0.26039 | |
| t Critical two-tail | 2.16037 | |

## 8. LIMITATIONS

Proposed method will fail if there is a vehicle overlapping or something blocked the camera view. Moreover proposed method is not illumination invariant. Shadows have an impact on overall performance and can create the problem in detecting the target region. Proposed method cannot be applied in night.

## 9. FUTURE IMPROVEMENTS

Further analysis is needed to overcome the above mentioned limitations. The use of longer camera battery could improve data collection. Survey was done mainly during the day, the driving behaviour may depend on the timing. Hence, further analysis can be conducted using different timings.

## 10. CONCLUSION

In this report, we have presented an image processing technique for finding vehicle path and length by automatically calculating the distance from the shoulder line and length of all segmented vehicles to detect heavy vehicles which have an impact on the pavement. The proposed technique was evaluated on data collected from the Warwick and Mackay regions. The results in terms of vehicle distance from shoulder line and length of vehicles have been obtained and included in this report. The results for WCLT show that as the distance from the shoulder increases the number of heavy vehicles increases. The results for single line show that as the distance from the shoulder line increases the number of heavy vehicles decreases.

We can conclude that there is a clear experimental evidence from Warwick region that drivers tend to drive close to shoulder line where we have a single middle line and drivers tend to drive away from the shoulder line (close to WCLT) where we have WCLT. However, the experimental evidence from Mackay region is that drivers tend to drive close to shoulder line where we have a single middle line and only some drivers tend to drive away from the shoulder line (close to WCLT) where we have WCLT.