Centre for Accident Research
& Road Safety - Queensland

Cooperative and Highly Automated Driving Safety (CHAD) Study

Work Package 3: Australian safety challenges for CAVs

D344 – Guidance for CAV on-road deployment
July 2023

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ACRONYMS

AD	Automated Driving. All driving tasks are being carried out by ADS, including steering, brake, and acceleration.
ADR	Australian Design Rules
ADS	Automated Driving System
AVs	Automated Vehicles, considering SAE level 3+
CAVs	Cooperative Automated Vehicles
C-ITS	Cooperative Intelligent Transport Systems
RR&ET	TMR's Road Rules & Emerging Technology team
RT/LV	Road Train/Long Vehicle

SAE	Society of Automotive Engineers
TMR/DTMR	Department of Transport and Main Roads, Queensland
ZOE2	SAE Level 4 CAV prototype vehicle (pictured on the cover page of this report) used for this project.

1 INTRODUCTION

1.1 BRIEF BACKGROUND AND AIMS OF WORK PACKAGE 3

The iMove Cooperative and Highly Automated Driving (CHAD) Safety Study (iMOVE project 1-008) has delivered a cooperative and automated vehicle (CAV) prototype research platform (ZOE2, pictured in the cover page) with local expertise, to deliver a comprehensive safety study that will inform government policy and direction.

This project is part of the Queensland Department of Transport and Main Roads' (TMR) CHAD Pilot intended to prepare for the arrival of CAVs to improve safety, mobility, and environmental benefits on Australian roads. There are several reports to show the CAVs have potential to reduce crashes due to the human error significantly. However, this technology may also introduce new safety challenges. This project focuses on safety impacts/implications of introducing CAVs on Australian roads and is divided into four work packages:

- Work package 1: Driving task transition in AVs
- Work package 2: C-ITS and AV integration, and benefits evaluation (this report)
- Work package 3: Australian safety challenges for CAVs in the dynamic road environment
- Work package 4: Public awareness and demonstrations.

Published reports for each work package are available on iMOVE's website (Safely deploying automated vehicles on Australian roads (imoveaustralia.com)). This document provides guidance for CAV's on-road deployment. It contains the findings of the CHAD Safety Study's Work Package 3 (WP3). WP3 was designed to identify Australian-specific safety-critical ('risky') scenarios relating to the interaction of CAVs with other road users and to determine and test potential mitigations for one selected scenario on-road. In addition to WP3, this report provides findings about the challenges experienced and identified by the project team while deploying such technology on public road while delivering demonstrations as part of WP4.

The methodology (Figure 1), to define the cases of interest is derived from projects conducted in Europe, respectively MOOVE[1] in France and PEGASUS[2] in Germany. An initial list of risky scenarios was drawn from experts' consultations in Australia and then out of the first list three scenarios were confirmed as truly unique to Australia via consultation with a panel of international experts. Following identification of three unique Australian scenarios, an extensive data collection exercise was undertaken utilising ZOE2. There were several specific data collection drives were carried out (about 250 hours of driving) focusing on selected three scenarios (Road trains/Long vehicles, Australian unique wildlife and Single Lane two way rural roads), as part of WP3 study scope. In addition to specific data collection for the selected scenarios, this report encompasses findings from broader activities, including those from WP4 and incidental data gathered during travels between Queensland University of Technology and RACQ Mt Cotton test tracks, experiments at these tracks, and dynamic demonstrations in locations like Shailer Park, Bundamba,

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[1] https://www.vedecom.fr/moove-securiser-la-conduite-autonome-grace-a-la-collecte-des-donnees-de-roulage/ (in French)

[2] https://www.pegasusprojekt.de/en/about-PEGASUS

Bundaberg, and Mount Isa. Data collected from these scenarios were then used to describe accurately the challenges, and explore solutions.

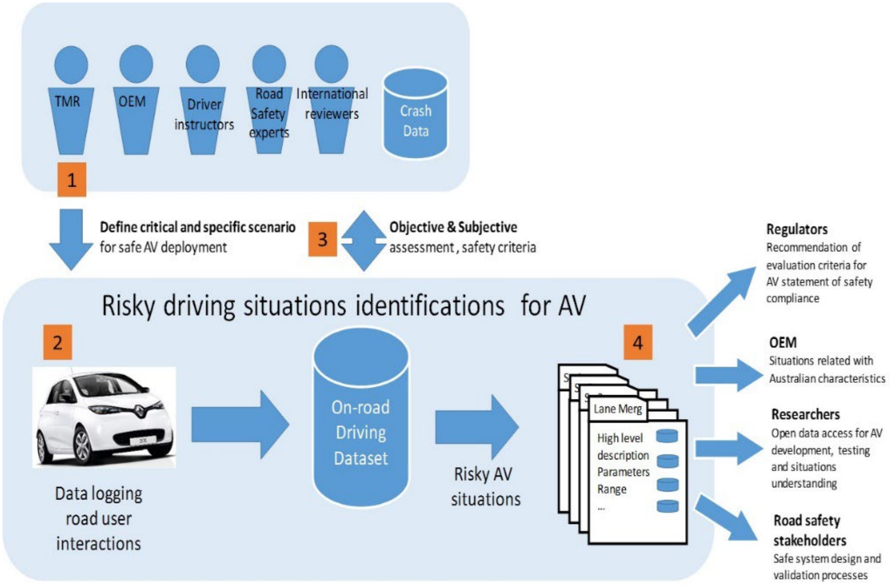

Figure 1 Methodology overview for WP3 (numbers are detailed in section 2)

These tasks and associated studies are outlined in a series of unpublished reports prepared as part of the iMOVE CHAD Safety Study project, including:

- For WP3:
    1. *Masoud M., Glaser S., Rakotonirainy A., WP3: D3.1.1 Study plan, June 2019.*
    2. *Masoud M., Demmel S., Glaser S., WP3: 3.2.2 Technical report – Data structure, April 2021*
    3. *Masoud M., Glaser S., Rakotonirainy A., WP3: D3.2.1 Technical report – Database Interface, June 2021.*
    4. *Masoud M., Demmel S., Glaser S., WP3: D3.4.1 Technical report – Risky Situation, October 2021*
    5. *Masoud M., Demmel S., Glaser S., WP3: D3.4.3 Technical report – Research Dataset Phase 1, March 2022*
    6. *Masoud M., Demmel S., Glaser S., WP3 : D3.4.2 Technical report – Baseline Road user Behaviour, June 2022*
    7. *Komol M., Wang L., Masoud M., Demmel S., Glaser S., WP3: D3.2.3 Technical report – Mitigation strategy for one scenario, July 2022*
    8. *Demmel S., Glaser S., WP3: D3.3.4 Technical report – Research Dataset Phase 2, May 2023*
    9. *Mohammed E., Evan N., Andry R., Sebastien G., Sebastien D., Mahmoud M., WP3: D3.4.5 – Improved CAV Interaction with Road Train/Long Vehicles, July 2023*

- For WP4 (Data collection during demonstrations):
    1. *Glaser S., Demmel S., Ghasemi Dehkordi S., Rakotonirainy A., WP4 : Demonstration report Shailer Park, Sept 2019*
    2. *Glaser S., Demmel S., Ghasemi Dehkordi S., Rakotonirainy A., WP4: Demonstration report Ipswich, Feb 2021.*

3. *Glaser S., Demmel S., Trivedi A., WP3: Demonstration report Bundaberg, June 2022.*
4. *Glaser S., Demmel S., Trivedi A., WP3: Demonstration report Mount Isa, July 2023.*

1.2 PURPOSE OF THIS DOCUMENT AND SIGNIFICANCE

The introduction of connected and automated vehicles (CAVs) holds immense promise for transforming the future of mobility, offering potential solutions to long-standing road safety challenges. The integration of CAVs has the potential to enhance road safety by minimizing human drivers' errors and their impact, improving traffic efficiency, and providing increased accessibility for individuals with limited mobility.

However, it is crucial to recognize that this technology also introduces new risks and complexities. For instance, (Favarò, Eurich, & Nader, 2017) analysed the detailed database from the California Department of Motor Vehicle (CaDMV, up to 2017) and showed the collision often results from human driver misunderstanding of the CAV behaviour and failure from the CAV to identify the correct dynamic behaviour. Furthermore, they found that CAVs are over-represented in the front position in rear-end collisions (In Figure 2) among the various scenarios, because of harsh reaction to the dynamic environment.

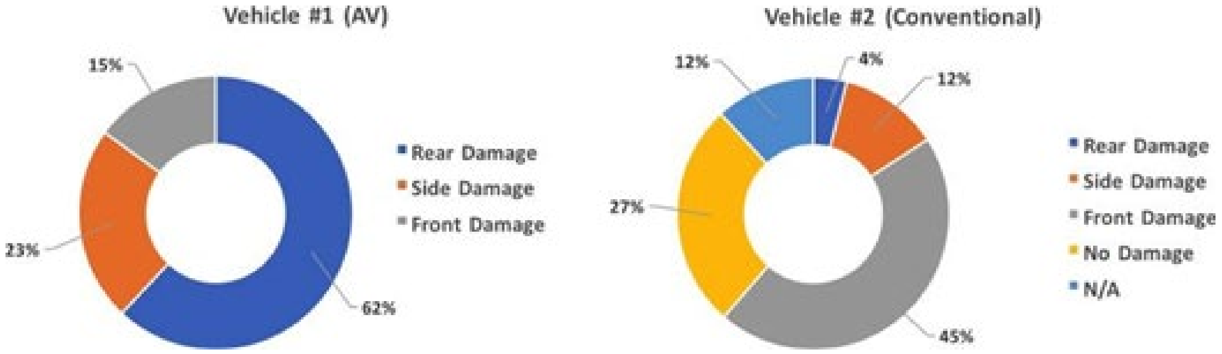

Figure 2 Automated car crash, damage location

The main functionality that CAVs must provide is to cooperate with other road users. A CAV must

(i) understand the overall environment (understand the road infrastructure, detect objects, and identify them)

(ii) predict the short-term future behaviour (what is the dynamic capability of other road users) and inform CAV's intention to the other road users and

(iii) react to the environment to ensure safety (minimizing longitudinal and lateral acceleration, maintaining a safe inter distance with the front vehicle, obey road rules etc.).

The knowledge about the dynamic driving environment is fundamental to better identifying safety problems encountered by CAVs in similar complex situations. However, the global development of Connected and Automated Vehicles (CAVs) predominantly occurs in major regions such as the United States, Europe, and China. In the Australian context, there is a limited presence of key players actively driving CAV innovations on open roads, as opposed to mining and farming environment. This situation poses a unique challenge as Australia faces unique circumstances and conditions that require attention at an international level, before the introduction of CAVs in Australia. The learnings, to address those specificities, may also benefit road safety internationally.

The primary objective of this work is to identify and address the Australian-specific safety-critical scenarios pertaining to the interaction of CAVs with other road users, ultimately contributing to the international knowledge on CAV deployment for Australia.

Section 2 focuses on the three identified unique Australian challenges and associated findings. Section 3 focuses on the findings from demonstrations delivered by the CHAD team utilising ZOE2 on the public roads. ZOE2 demonstrations discussed in this section are not part of WP3, however they provide additional findings, in Australian context, for the CAV deployment. Section 4 details current Australian CAV trial regulatory framework. Section 5 details findings and recommendations for the CAV deployment.

2 UNIQUE AUSTRALIAN SCENARIOS

2.1 INTRODUCTION AND METHODOLOGY

2.1.1 METHODOLOGY

2.1.2 ETHICS APPROVAL

The Queensland University of Technology (QUT) Human Research Ethics Committee (UHREC) has reviewed and accepted this study under the UHREC Reference number 2000000532 the 18 of September 2020 (until 18/09/2023). Two variations were raised and approved:

- On the 22/02/2021: modification in the initial research team, with the addition of three researchers
- On the 22/06/2021: for the addition of a sensor (eye tracker) and the addition of a professional driver.

Given the sensitivity of the data, such as images with identifying features, the application was considered as high risk. The ethics application approval is subject to conditions, limiting the database access and publication.

2.1.3 METHODOLOGY

The methodology was defined from previous international projects and in consultation with the Queensland Department of Transport and Main Roads. Steps labelled in the Figure 1 are described in this section.

The study comprises two key phases – the first phase sought to understand current road user behaviour and identify 'risky' scenarios for their interactions with CAVs; the second phase implemented a mitigation strategy for one of those 'risky' scenarios and evaluated the resulting change in road user behaviour and safety impact.

2.1.3.1 *PHASE 1*

- **STEP 1** – Use case and critical scenario definition:

The scenarios and use cases relevant for the project have been defined and described in detail, in consultation with the road safety experts. An initial list of the scenarios were discussed with subject matter experts from QUT, TMR (Engineering and Technology team) and TMR (AV regulation team). The relevance of these scenarios were further assessed with international experts to ensure that the project only focuses on unique Australian scenarios which may create safety issues for CAVs. Data on vehicle crashes and road safety risk assessments were also used to arrive upon initial list of the scenarios. Further details on these activities are in Section 2.2.

- **STEP 2** – Data collection:

The data gathering was focused on the scenarios described in Step 1. Specific data collection drives conducted over a long period of time (more than 30 days), between Brisbane and Ipswich, as well as limited runs between Brisbane and west of Dalby. This reference database covered varied traffic and weather conditions, as well as day and night conditions. More than 200 hours of driving data was collected utilising ZOE2.

- **STEP 3** – High-level descriptions and interaction:

From the collected data, the relevant descriptions and parameters of the behaviour of surrounding vehicles were extracted from the high-level data and were used to define a statistical representation of the road users' behaviour for the use case under scrutiny. Some of these behaviours ('risky' situations) are considered within recommendations and mitigation stage (Step 4).

- **STEP 4** – Recommendations and mitigation strategies:

Key output of this step is a list of 'risky' situations which a CAV will need to deal with in a safe manner. Mitigation strategies for the 'risky' situations is then recommended across a range of interventions – including algorithm improvement for path planning and decision-making (that is, new active safety functions), restriction of operational design domains, infrastructure improvements, changes to road rules, and driver and public education.

The final deliverable from Phase 1 comprises:

- a report summarising the baseline of existing road user interaction behaviour in Australia,

Further information concerning the detailed behaviour can be found in "*Masoud M., Demmel S., Glaser S., WP3 : D3.4.2 Technical report – Baseline Road user Behaviour, June* 2022".

- a report on Australian safety challenges/ mitigations for CAV,

Further information concerning the mitigation strategy can be found in "*Komol M., Wang L., Masoud M., Demmel S., Glaser S., WP3: D3.2.3 Technical report – Mitigation strategy for one scenario, July 2022*".

- a report detailing the CAV deployment challenges in Australia, is detailed in this report.

2.1.4 *PHASE 2*

In Phase 2, it was intended to analyse the behaviour of the road users when the vehicle is in automated mode on the selection of one 'risky' scenario and its mitigation strategy for further testing. The mitigation should be based on a CAV algorithm improvement for path planning/ decision-making.

Because of the technical limitation of ZOE2, that is its maximum speed in automated mode is limited to 50kmph, it was not possible to conduct on-road research using the CAV in fully automated mode. To overcome this limitation an HMI interface was developed and implemented in ZOE2, whereby ZOE2's ADS communicated its driving intentions to the expert driver who in turn manually drove ZOE2.

The results of the implemented mitigation strategy is detailed in the report "*Mohammed E., Evan N., Andry R., Sebastien G., Sebastien D., Mahmoud M., WP3: D3.4.5 – Improved CAV Interaction with Road Train/Long Vehicles, July 2023."*

2.2 SCENARIOS AND EXPERTS' VIEWS AND INSIGHT

The following table shows the initial list of 'risky' scenarios. Of these, 11 use cases were provided to the international experts for their opinion. Five use cases (number 12 to 16), did not reach sufficient consensus to be progressed to the international experts. The "hook turn" use case (Id 16) was discarded as this manoeuvre does not apply to Queensland. Details about the use cases in the table below are contained in the report "*Masoud M., Glaser S., Rakotonirainy A., WP3: D3.1.1 Study plan, June 2019.*"

Id	Use Case	Description	CAV Component
1	Fatigue-related collision	Travelling long distance during normal sleep times can cause fatigue, reduction in driving or riding ability. Accordingly, most serious crashes, a head-on crash, can occur. An AV must be aware of the possibility of vehicle driving in the same lane, but in the wrong direction. Due to vast distances fatigue related driving exposure is higher in Australia.	Situation understanding
2	Hit animal	In Australia, Kangaroos and Wallabies are most common animals that can cause hit animals type crashes with a lot of damage to the vehicle during panic and swerve. Moreover, these animals present patterns of movement which are not common.	Sensing
3	Overtaking on left and right	In Australia, the driver can overtake on the left or on the right directions. Accordingly, overtaking on both sides can cause crashes. While generating an overtaking manoeuvre or changing its lane, an AV must be aware of such situation.	Sensing, situation understanding
4	Road trains / heavy vehicle/ long vehicle	In Australia, one of the common transportation means is the multiple vehicles (road train) which sometimes reach more than 50 meters in length and nearly 200 tonnes in weight. Using road trains with unexpected road conditions can cause road crashes and fatalities. Road trains are not common overseas moreover they, as a dynamic object, have limited capabilities in term of reaction (handling and braking).	Sensing, situation understanding
5	Remote area with only one lane/two ways Dust and unsealed road	In Australia, not all roads are sealed with bitumen, and this can affect negatively on driving performance, where the vehicle is not stable on the road. Also, the main feature of these roads is one lane/two driving directions, which increases the possibility of crashes.	Sensing, decision
6	Flooded road	The flooded roads are a fairly common sight in Australia even on suburban roads. Using road signs to warn the vehicle driver is most commonly used as a mitigation strategy. On such cases, an AV must understand if some route cannot be used due to flooding.	Situation understanding
7	Overtaking and merging	When some lanes are closed, drivers must merge by giving way to other vehicles in the same direction adhering to overtaking and merging rules. AVs will need to negotiate such manoeuvres. It is important to note, from 1200 drivers surveyed, 86% of drivers had reported they have not been "let in" to merge when it clearly was their turn, and 9% admitted not letting other drivers' merge.	decision
8	Intersection with different stop lanes, or stop lane far from the intersection lane	At some intersections with multi lanes, the stop lines are staggered. This can affect AV's visibility affecting its ability to understand dynamic traffic flow through the intersection.	Situation understanding
9	Zipper merge, without lane marking	Merging with one or more other lanes of traffic travelling in the same direction with no markings or lanes lines.	Situation understanding

10	Different type of lane marking	The driver is not permitted to overtake another vehicle by crossing a single continuous dividing line or a single continuous dividing line to the left of a broken dividing line or 2 parallel continuous dividing lines.”	Sensing, situation understanding
11	Successions of uphill and downhill	Some areas are hilly, and the succession of up-hill and down-hill may limit the sensing range of the vehicle.	Sensing
12	Making a right turn from a road with no road marking	At an intersection with no dashed lines to guide the right turning vehicle, the driver must judge potential conflict while turning due to lack of guidelines.	Discarded
13	Pedestrian on a left turn slip lane.	Slip lanes allow drivers to turn left at red lights at the intersection, as long as they give way to pedestrians and oncoming vehicles. An AV will need to consider the unexpected pedestrian and merge with the flowing cross traffic.	Discarded
14	Parked vehicle on the roadside legally	In Australia some roads with speed limit of 60kmph, left most lane is used for parking during off peak hours. In this case, an AV will need to reliably detect legally parked vehicles and merge into adjacent lane.	Discarded
15	Merged multi lanes	In this case, multi lanes are merged to the highway’s one lane in a relatively short distance.	Discarded
16	Hook turn	Hook turn is from the Victoria Road rules initially to manage intersection where vehicles have to go to the right and cross a tramway lane.	Discarded

Three international experts reviewed the 11 use cases, and they evaluated them using three criteria: 1/ the uniqueness to the Australian environment, 2/ the ability to implement these use cases, and 3/ the novelty and impact in terms of safety and interest for the community.

International expert’s recommendations are in the table below, where ‘*Very specific’* means all three criteria are met, ‘*less specific’* means the use case is relevant (addressing some but not all criteria).

Use Case	Expert 1	Expert 2	Expert 3
Single Carriageway, single lane with two ways	Very specific	Less specific	Less specific
Road Trains, Long Vehicles	Very specific	Very specific	Less specific
Australian wildlife	Very specific	Less specific	Very specific
Left- turn slip lanes		Less specific	
School Zone		Less specific	
Flooded roads	Less specific	Very specific	Less specific
Intersection with staggered lines			
Overtaking and merging lanes			
Overtaking lane, with priority to the fastest lane			
Fatigue related collision			
Succession of uphill and downhill	Less specific		
Different type of lane marking	Less specific		Very specific
Overtaking on left and right			

Figure 3 Selected use cases, pictures from ZOE2 data collection (Single lane two way rural roads, Road Train and Australian wildlife)

Based on the previous table and scope requirement of selecting three use cases, the first three uses cases were selected[3] (Single Lane two-ways rural roads, Road trains/long vehicles, Australian unique wildlife) to be considered for the data collection in different environmental conditions (See Figure 3). It is worth noting that:

- Remote and rural related use cases (such as the Single Lane two-way rural roads) have been described as potentially far away, as they are not the focus of major companies. Urban use cases demonstrate a far higher return on investment.
- Some scenarios may be easily solved in a communicating environment. Large companies may not include the functionalities in their ODD unless a certain level of communication maturity is reached (for instance, the merging use case with a short acceleration ramp or the school zone).
- Several scenarios are not Australia specific, but the exposure in Australia is at a different level. They are internationally dealt with by stopping the AV operation, and this solution in Australia may be too disruptive (for instance, the flooded road).

Section 2.3 analyses of the above three selected use cases.

Findings:

- Three use cases were identified as unique to Australia. These were:
    1) Road Trains/Long Vehicles,
    2) Single lane two-way rural roads, and
    3) Wildlife, Kangaroos and Wallabies.
- Urban use cases are likely to be implemented much earlier than the use cases related to remote and regional environments, such as Single Lane two-way rural roads.
- Some scenarios, such as merging with short acceleration ramp and school zones, can easily be delivered if communication technologies (C-ITS messaging) are implemented.
- Several scenarios (such as flooded road) are not unique to Australia, however their exposure in Australia is much higher. In such scenarios, stopping the CAV and seeking human intervention may be too disruptive.
- Very specific scenarios, such as hook turn in Victoria, has not been assessed in this study.

Recommendations:

- Regulators should limit the Operational Design Domain (ODD) of the CAV if supporting technologies for safe operation (such as C-ITS messages, accurate high-definition maps) are not available.

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[3] A new project '*Expanding Operating Design Domain of Automated Vehicles'* exploring some of the remaining use cases is currently underway.

2.3 SPECIFIC USE CASES AND INSIGHT FROM COLLECTED DATA

2.3.1 ROAD TRAINS

2.3.1.1 ROAD SAFETY STATISTICS

Road Trains (RT) and Long Vehicles (LV) are a common sight in Australia. They are transporting minerals, materials from mines, fresh goods, and cattle from farms. They cover long distances from remote and rural Australia to freight centres where the trailers of the RT/LV are separated and attached to Conventional Trucks.

A Road Train (RT) may be over 50 meters long and can weigh up to nearly 200 tonnes, which includes the combinations of Trucks and trailers. Long Vehicles (LV) are trucks between 22 to 30m in length however in some oversize transportation tasks (transporting windmill blades) the Long Vehicle could be as long as 100m in length. For this study all vehicles 22m and above are subject to investigation as they are unique to Australia.

RT/LVs are unique to Australia, and Automated Driving Systems (ADS) must understand their uniqueness, such as the dimensions and the dynamic behaviour, that differ drastically from other vehicles. It means that the first step is to identify them correctly.

To understand the safety risk of RT/LVs, crash data was extracted from the QLD crash database. Based on QLD crashes database, from January 1, 2001, to December 31, 2020, the crashes that involved trucks were 25,753 (out of 353,651), and the total number of trucks in these crashes were 27,125. The crashes casualty has been highlighted in Table 1. Please note the data in table below does not distinguish between conventional trucks, RTs, and LVs.

Table 1 Crash statistics for trucks/ LV/ RT use cases

	Total Crashes	Count Casualty Fatality	Count Casualty Hospitalised	Count Casualty medically treated	Count casualty Minor Injury	Total casualty
All crashes	353,651	5,227	127,476	146,024	76,030	355,257
Involved Truck	25,753	1,018	8,926	9,393	4,839	24,176
Truck crashes percentage	7.282	19.475	7.0021	6.4325	6.3646	6.8052

2.3.1.2 COLLECTED DATA

Data collections, using ZOE2, for this use case occurred at Dalby (two data collections of respectively 4 days and 3 days), Charleville (during the static display as part of WP4 activities) and Mount Isa (in conjunction with the dynamic demonstration, as part of WP4 activities). The assessment of the collected data provided the following insights.

2.3.1.3 INSIGHTS

- Sensing:

The main concern related to the RT/LV is the lack of proper category related to this specific type of vehicles from different sensors and algorithms (Camera, Lidar, and Radar). RT/LV differ from the conventional truck by their dimensions as well as dynamic capabilities, therefore it is critical to accurately identify and classify them as RT/LV.

Camera: The camera accurately captures the object bounding box but incorrectly classifies it as a conventional truck using either available intelligent camera or state-of-the-art algorithms. The bounding box created by the system produces cropped bounding boxes compared to the real dimension of the vehicle.

Lidar: The points cloud is appropriately generated as per the dimensions of the RT/LV; the obstacle is well detected, so the initial points cloud signal is accurate. The points cloud cluster (bounding box) generated by the lidars often fails to extract the right dimension from the vehicle's points cloud, leading to incomplete bounding box, and at times missing trailer in the bounding box. The bounding box of a RT/LV in lidar detection demonstrates the limitation when the RT/LV is articulated, especially when trailers are connected with a long draw bar instead of a turn table (Figure 4). The algorithm fails to create a sufficiently large bounding box around the entire length of the vehicle.


(a) (b)

Figure 4 (a) Trailers connected with draw bar (also known as dog trailer), (b) Trailers connected on turn table.

Radar: This sensor often captures only the axles of the vehicle, ignoring the overhang, thus from behind the sensor overestimates distance to the road trains. One of the advantages observed of this sensor is that it provides more reliable detection, especially when seeing the vehicle from the side.

- Decision making:

It became obvious that in the seeing mechanism (sensors), detection and classification are already unreliable for the RT/LV scenario. Since classification cannot be achieved reliably it will be difficult to move on to the next phase of ADS in relation to tracking over time, decision making and planning.

In general, the decision-making mechanism in relation to RT/LV will need to consider the length and dynamic characteristics of the RT/LV, especially when the AV is following the RT/LV. The ADS will need to consider RT/LV's poor deceleration characteristics and length especially when overtaking.

2.3.1.4 PROTOTYPING EXPERIMENTS

As briefly explained in Section 2.1.4, the CHAD team developed and implemented a prototype solution in ZOE2 with an aim to answer two exploratory questions.

1. Is it possible to detect and classify RT/LT accurately by using currently available open-sourced machine learning techniques?
2. Can rule based decision-making mechanisms produce safe interaction between CAV and RT/LV?

The results of the above experiments suggested; 1) currently available open-sourced machine learning techniques along with sensor fusion techniques can accurately detect and classify RT/LV, however it will require large amount of data to train the algorithms due to varied shapes and size of RT/LV on Australian roads, 2) Rule based decision-making mechanisms can produce safe interactions however accurate high-definition maps of the road becomes a critical element for the overtaking manoeuvres.

Detailed results of this prototyping experiments are contained in the report “*Mohammed E., Evan N., Andry R., Sebastien G., Sebastien D., Mahmoud M., WP3: D3.4.5 – Improved CAV Interaction with Road Train/Long Vehicles, July 2023.*”

Findings:

- Off-the-shelf perception systems are not suitable for accurately detecting and classifying RT/LVs.
- Decision-making mechanisms must consider RT/LV length and dynamic characteristics.
- Machine learning techniques along with sensor fusion techniques can accurately detect and classify RT/LV.
- Rule based decision-making mechanisms utilising accurate high-definition maps of the road are likely to provide safe interaction between CAV and RT/LV.

Recommendations:

- ADS developers will need to ensure their perception systems are able to accurately detect and classify RT/LV including its length.
- ADS developers will need to ensure their decision-making mechanisms consider the length and dynamic characteristics of the RT/LV, especially during the overtaking manoeuvres.
- Regulators need to seek safety case from the ADSE (Automated Driving System Entity) demonstrating AV’s safety remain ‘*so far as is reasonably practicable’* while interacting with RT/LV on Australian roads.

2.3.2 SINGLE LANE TWO-WAY RURAL ROADS

2.3.2.1 SAFETY STATISTICS

Some roads have a limited width in Australia where only one vehicle can drive on a sealed lane. The road’s shoulder is often stabilised but not sealed and includes gravel, sand, or dirt. These roads can negatively affect driving performance, where the vehicle is not stable on the road. Also, dry weather can cause dusty conditions and affect sensor visibility.

To understand the safety risk such narrow roads, crash data was extracted from the QLD crash database. Based on QLD crashes database, from January 1, 2001, to December 31, 2020, the crashes of one lane two-direction roads were 9,379 (out of 353,651), while the total casualty was 10,697 (out of 355,257). More details have been highlighted in Table 2.

Table 2 Crash statistics for the Single lane two way rural roads use case

	Total Crashes	Count Casualty Fatality	Count Casualty Hospitalised	Count Casualty medically treated	Count casualty Minor Injury	Total casualty
All crashes	353,651	5,227	127,476	146,024	76,030	355,257
One lane and two directions roads	9,379	276	4,768	3,713	1,940	10,697
One lane and two directions roads percentage	2.652	5.2803	3.7403	2.5427	2.5516	3.0111

2.3.2.2 COLLECTED DATA

Data collections for this use case occurred at Dalby (two sessions) and Charleville (during the static display as part of WP4 activities). The assessment of the collected data provided the following insights.

2.3.2.3 INSIGHTS

The one lane two-ways roads are common in regional Australia, where the traffic is sparse. The usual configuration is a 4-metre-wide sealed lane, allowing a large truck to drive on it, but unable to accommodate two crossing vehicles. These roads have large, unsealed shoulders and do not contain lane markings. Such a road structure creates several challenges.

- Sensing (determining road structure):

No lane marking affects the lateral positioning of the AV on the road. Further the current understanding of the drivable space is no longer valid as the unsealed shoulders are now considered driveable space. Despite progress in Machine learning, algorithms fail to correctly identify this road environment.

Further, limited mobile network accessibility in such environment would result in reduced GPS positioning accuracy (no corrections received). Improving positioning accuracy by comparing features with the onboard high-definition maps are also challenging due to the environment presenting limited features.

Dust can impact the sensing and tracking of objects. When crossing another vehicle, the dust from the shoulder may obstruct the sensor’s field of view or create fake obstacles.

- Decision (applying local road rules)

Road rules suggest differing behaviour during AV interaction with road users and need to be implemented accordingly. Two crossing vehicles (such as cars) are suggested to drive partially on the shoulders, however during crossing a conventional truck/RT/LV it is suggested the AV completely drives on the shoulder giving full width of the lane to the oncoming conventional truck/RT/AV.

2.3.2.4 PROTOTYPING EXPERIMENTS

No mitigation strategies were developed and prototyped as the project scope only included one scenario for the prototyping. Due to this limitation, no technical recommendations are made. Another project titled ‘Expanding Operating Design Domain of Automated Vehicles’ may produce prototype experiments for this scenario.

Findings:

- Accurate lateral positioning of the AV is difficult to achieve.
- Reliable detection of driveable space will be challenging.
- Dust may affect the sensor’s field of view.
- Decision-making mechanisms need to implement different set of rules depending upon the type of vehicle the AV is interacting with.

Recommendations:

- Expand the study scope of future projects to prototype and confirm mitigation strategies for the scenario.

2.3.3 AUSTRALIAN UNIQUE WILDLIFE

2.3.3.1 ROAD SAFETY STATISTICS

International experts believe that the Australian wildlife scenario is a significant traffic safety challenge in rural and suburban environments. The specific challenges here are the ’ADS' animal recognition and tracking, which need to be improved because of the unusual characteristics of some Australian wildlife (kangaroos and wallabies), especially in their motion patterns.

According to the NRMA insurance, around 16,000 collisions with kangaroos a year are reported. Also, based on QLD crashes database, from January 1, 2001, to December 31, 2020, the animals' crashes were 3,324 (out of 353,651), while the total casualty was 2547 (out of 355257). More details have been highlighted in Table 3.

Table 3 Crash statistics for the wildlife use case

	Total Crashes	Count Casualty Fatality	Count Casualty Hospitalised	Count Casualty medically treated	Count casualty Minor Injury	Total casualty
All crashes	353,651	5,227	127,476	146,024	76,030	355,257
Involved Animals	3,324	36	1,191	878	442	2,547
Animal crashes percentage	0.9399	0.6887	0.9343	0.6013	0.5813	0.7169

2.3.3.2 COLLECTED DATA

There were no data collected in relation to this scenario, despite efforts made during various regional travels by ZOE2. Zoos and wildlife centuries were contacted to organise data collection activities on their sites however these efforts were not successful. Another project titled 'Expanding Operating Design Domain of Automated Vehicles' may be able to collect required data and produce prototype experiments for this scenario.

Findings:

- Kangaroo/Wallaby interaction data is very difficult to collect.

Recommendations:

- Expand the study scope of future projects to prototype and confirm mitigation strategies for the scenario.

3 ZOE2 TRIALS ON PUBLIC ROADS

This project's work package 4 delivered four dynamic demonstrations of ZOE2 on public roads. Two of these demonstrations were delivered in the southeast Queensland while the remaining two were delivered in the regional Queensland. At the end of each demonstration a detailed report[4] was produced and submitted to the regulator. Learnings from each of these demonstrations are summarised in this section.

3.1 SHAILER PARK DEMONSTRATION

Shailer Park was ZOE2's first Australian demonstration on public road. Working with the VEDECOM Tech development team, the project team had to adapt the ADS to the Australian driving context which differs from the European (driving side, road rules). During the demonstration, ZOE2 drove in automated driving mode over approximately six-kilometre route through actual traffic conditions. The demonstration successfully showed ZOE2's capability to negotiate roundabouts, intersections, up/down hills and turns at speeds of up to 50 km/h. This was Australia's first demonstration where an AV negotiated real traffic conditions at speeds of up to 50 km/h.

The main challenges were related to:

- Succession of uphill and downhill:

While uphill or downhill roads are not unique to Australia, the Shailer Park route presented a strong slope variation in succession. Due to the slop, ZOE2's field of view was reduced on some road sections and the speed had to be adapted accordingly to be able to react to any unforeseen circumstances. This highlighted a need for strategically positioning ADS's sensor suite which provides optimum field of view in various road topography.

- Reflectors combined with uphill roads:

Reflectors are not unique to Australia, however when they are positioned inside the lane on uphill roads they produce strong LIDAR reflection. These, depending on the ground's slope, are detected as static obstacles by the LiDARs and often categorised as cyclists. These false-positive obstacles are intruding into the vehicle's path resulting in deceleration of the vehicle until the slop angle reduces and the obstacle disappears. At times, this deceleration can be sudden and harsh. Robust sensor fusion based perception system taking inputs from varied sensors, such as LIDAR, Radar and Camera, will eliminate such false-positives.

3.2 IPSWICH (BUNDAMBA) DEMONSTRATION

Bundamba demonstration was delivered in March 2020, where a total of 73 participants were able to experience on-road automated driving in ZOE2. During the demonstration ZOE2 drove public participants, in automated mode, on a 4.5 km suburban route. The route contained manoeuvres through three

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[4] Demonstration report – Shailer Park, Sept 2019
Demonstration report – Ipswich (Bundamba), Feb 2021
Demonstration report – Bundaberg, June 2022
Demonstration report – Mount Isa, July 2023

roundabouts, public carpark, residential streets, and a U-turn on a cul-de-sac up to speed of 50kmph. There were no new challenges found in the context of unique Australian environment.

3.3 BUNDABERG DEMONSTRATION

Bundaberg was the first regional demonstration for ZOE2, which was delivered in June 2022. The road infrastructure at Bundaberg did not differ much from the previous demonstrations (lane markings, road signages, etc), except for the road widths which were wider. During the demonstration ZOE2 drove in automated mode, with speed up to 50kmph, on a 4.5km route. The demonstration was delivered for a week providing 118 public participants an automated driving experience. On the demonstration route, ZOE2 negotiated 24 intersections (all unprotected intersections) including turning right on four intersections, two pedestrian crossings and two school zones.

The main challenge observed include:

- Producing a naturalistic driving behaviour at intersections:

Monitoring and path planning at unprotected intersections (especially when turning right) was found to be challenging as predicting behaviours of road users was a very difficult task. This issue is very well known by the AV technology developers and there is a significant research and development in this area to ensure the AVs behave as naturalistic as humans in the local environment.

3.4 MOUNT ISA DEMONSTRATION

Mount Isa was the second regional demonstration by ZOE2 and was delivered in July 2023. The physical infrastructure was like Bundaberg. Other drivers' observed behaviour was also very similar. The vehicle types at Mount Isa were different with a large representation of utility vehicles, 4WDs, vehicles with trailers, recreational vehicles and steady flow of road trains on the Barkly Highway. Public dynamic demonstration of ZOE2 was delivered over a week in July 2023 and was the most complex dynamic demonstration by CHAD team, so far. The 5.5 km route included ZOE2 navigating through two traffic light intersections, two lane merges, four pedestrian crossings, two slip lanes, one lane change, one roadwork zone, one school zone and one roundabout. A total of 43 runs were carried out over the demonstration week, proving automated driving experience to 80+ public participants.

The main challenges observed include:

- Vehicle types:

Interaction with large vehicles such as 4WDs with trailer, heavy-vehicles and road trains was found to be challenging. While accurately detecting and predicting their dynamic behaviour is a challenge (refer to Section 2.3.1), they also restrict sensor visibility at intersections due to their size. Considering large size of some of these vehicles, strategically locating sensors at high position may not be enough. To deal with such circumstances an AV will need to make certain assumptions and adjust its own driving behaviour to ensure safety. IEEE 2846:2022 standard proposes assumptions for ADSs to deal with such situations.

- Vehicle with overhung load (such as ladder):

Detecting an overhung load such as a ladder in the back of a utility vehicle is found to be challenging. Modern detection techniques such as VIDAR (Visual Lidar) in conjunction with sensor fusion should be able to provide detection assurance.

- Extra polite drivers:

Sometimes other vehicles gave way to ZOE2 even though they didn’t need to (for example, slowing or stopping in a through lane to let ZOE2 merge in front of them). Such circumstances are challenging for an AV as it would need to be able to detect another vehicle’s intentions (for example, that it has stopped to let the AV in) and drive assertively. While human drivers can do this based on observing both the vehicle and driver behaviour (such as a wave or flash of lights), it’s not clear how an AV would sense and combine these inputs to make a decision. This will be an important aspect of AV advancement to ensure there are no unintended congestion impacts.

Findings:

- Succession of uphill and downhill road topography reduces AV’s field of view.
- Reflectors located inside the lane on uphill roads produce strong LIDAR reflection, increasing likelihood of a harsh braking event.
- Producing a naturalistic driving behaviour is difficult and needs to consider local road user behaviours. These behaviours could be aggressive or extra polite.
- Strategically locating sensors at high position may not be enough to improve sensor field of view.
- Overhung loads, such as ladder in the back of a utility vehicle, are difficult to accurately detect.

Recommendations:

- ADS developers will need to;
  - strategically locate their sensors to optimise field of view,
  - implement robust sensor fusion based perception system taking inputs form varied sensors, such as LIDARs, Radars and Cameras,
  - demonstrate their ADS produces naturalistic driving behaviour in the Australian environment,
  - ensure, at minimum, IEEE 2846:2022 proposed assumptions are implemented,
  - implement modern detection techniques such as VIDAR in conjunction with sensor fusion techniques to provide high degree of detection assurance.

4 EXISTING REGULATORY FRAMEWORK

Australia is currently drafting an AV national law, associated regulatory framework and national AV regulator. The Australian regulatory regime for AVs is expected to be implemented by 2026. In the meantime, in Queensland, TMR's Road Rules & Emerging Technology (RR&ET) team facilitates AV trials using a range of existing legislative mechanisms and in line with the National Transport Commission's Guidelines for Trials of Automated Vehicles (AVs) in Australia. This includes the ability to exempt some road rules and vehicle standards requirements.

TMR offers an integrated approach to obtaining permits and approvals. This includes:

- Providing in-principle support for the importation of trial vehicles and working with the Commonwealth Government to expedite importation approvals, where possible.
- Supporting trial applicants to register trial vehicles, obtain an AV Trial Permit and any relevant passenger transport authorisations, with a single point of contact into the department.
- Helping to navigate any police permitting requirements and brokering introductions with local and state police representatives.
- Brokering introductions with other key stakeholders, including other emergency services and local governments.

The Queensland approach to regulating trials is flexible and able to accommodate a range of deployment options. To enable this, the approach to safety assurance is adapted based on each trial proposal. TMR issues an AV Trial Permit to trial an AV on Queensland roads and road-related areas following a review of the AV Trial Permit application. All dynamic demonstrations described in section 3, were subject to AV Trial Permit framework and received an AV Trial Permit with certain conditions before demonstrations were delivered.

4.1 AV TRIAL PERMIT APPLICATION

The Trial Permit applications for demonstrations mentioned in section 3 were submitted by QUT to TMR's RR&ET team. The application contained information about:

- Trial objectives
- Trial's Operational Design Domain considering proposed vehicle's limitations
- Trial location including traffic volumes, crash data, presence of school zone, presence of vulnerable road users, obscured driveways or road entries and so on
- Transport Operations (Passenger Transport) Act 1994, obligations and associated actions
- Vehicle driver/supervisor suitability requirements
- Accessibility related actions meeting Disability Standards for Accessible Public Transport 2002
- Local council support
- Community engagement
- Stakeholder management
- Change management
- Vehicle details including vehicle technology

- Compliance with *Transport Operations (Road Use Management – Vehicle Standards and Safety) Regulation 2021* and required exemptions
- Compliance with *Transport Operations (Road Use Management – Road Rules) Regulation 2009* and required exemptions
- Vehicle import approval
- Vehicle registration information
- Test and validation procedures
- Safety management including general and route specific risk assessments and associated safety management plans
- Traffic management plans

4.2 AV TRIAL PERMIT

Following a review by TMR's RR&ET team, QUT was issued an AV Trial Permit with the following conditions and exemptions.

4.2.1 EXEMPTIONS

The AV Trial Permit granted following exemptions:

1) ***Transport Operations (Road Use Management – Road Rules) Regulation 2009***

   Pursuant to section 128 of the *Transport Operations (Road Use Management – Accreditation and Other Provisions) Regulation 2015*, authorised persons for this permit are granted an exemption (Special Circumstance Permit) from the following provisions of the *Transport Operations (Road Use Management – Road Rules) Regulation 2009* in relation to the operation of the vehicle in ***automated mode***:

   - Rules regarding a driver maintaining proper control: sections 297(1) and 297(2).

2) ***Transport Operations (Road Use Management—Vehicle Standards and Safety) Regulation 2021***

   Pursuant to section 54 of the *Transport Operations (Road Use Management - Vehicle Standards and Safety) Regulation 2021*, the vehicle is permitted to operate under a Safe Movement Permit, with exemptions from compliance the following Australian Design Rules (ADR) as required under Schedule 1, section 22-:

   - ADR 10 Steering Column
   - ADR 31 Brake Systems for Passenger Cars
   - ADR 42 General Safety Requirements
   - ADR 69 Full Frontal Impact Occupant Protection
   - ADR 73 Offset Front Impact Occupant Protection.

4.2.2 CONDITIONS

The granted AV Trial Permit was subject to several conditions some of these are:

<u>General conditions</u>

1. The permit holder has an overriding obligation to ensure the safe operation of the vehicle and must take all reasonable steps to ensure that the safety of any persons interacting with the vehicle or the trial is not adversely impacted.

2. The permit holder must obtain all relevant permits, approvals, accreditations and consents prior to conducting the trial and ensure that these remain in place when the vehicle is in operation.

3. The permit holder must ensure that the operation of the vehicle and the trial complies with the safety management plan and other supporting documentation that were submitted and approved by DTMR as part of the permit application. This includes an obligation on the permit holder to conduct all pre-trial testing and maintain all risk treatments.

4. The permit holder must have comprehensive insurance for the vehicle and the trial, including public liability insurance for at least AUD$20 million and appropriate product liability insurance. Insurance policies must expressly cover personal injuries and death as well as property damage caused by, or in relation to, the operation of the vehicle on both private and public land and roads. Insurance policies must remain in force at any time the vehicle is in operation and note the State of Queensland's interest on the insurance certificate(s).

5. The permit holder must not object to being joined as a party to any legal claim made against the State of Queensland acting through DTMR in relation to any matter arising from the grant of this permit or the conduct of the permit holder.

6. The permit holder must make available relevant contact details in a public manner to enable community members to ask questions or make complaints about the operation of the vehicle.

7. The permit holder must grant access to DTMR officers to the vehicle and trial locations at any time for the purposes of monitoring compliance with this permit. DTMR may conduct any test on, or make any assessment of, the vehicle to determine that it can be operated safely. The nature of these tests or assessments can be determined by DTMR given the relevant circumstances.

Reporting

8. The permit holder must notify a serious incident to DTMR by phone and/or email as soon as practicable and provide a written report within 7 days.

9. The permit holder must notify a non-serious incident to DTMR within 48 hours by phone and/or email and provide a written report within 7 days.

10. The permit holder must provide DTMR copies of any additional reports related to the trial or operation of the vehicle.

11. The permit holder must provide other ad hoc reporting to DTMR, if requested in writing to do so by DTMR. So far as reasonably practicable, ad hoc reporting requests should be completed within 48 hours.

4.3 TRIAL PERMIT PROCESS

The CHAD team have had several meetings with the RR&ET team during the trial permit process. The RR&ET team provided guidance as and when required and provided contact details of stakeholders whose approval/consultation was required. The process is found to be efficient and effective in mitigating and managing both community expectations and road safety risks.

During the permit process it became obvious that;

- the need for granting exemptions from certain regulations is not sustainable in three to four years horizon, when manufacturers will start manufacturing such vehicles a mass. Noting, the current trial permit framework is an interim solution while Australia awaits AV national law and national regulator in 2026. The implementation timeframe for the AV national law and national regulator, in our opinion, is reasonable.
- the consultation with the local law enforcement agency and first responders is found to be suitable and sufficient for the short-term trials with safety driver on-board. However, large scale driverless trials/deployments in the future will require significant efforts to develop and implement training and associated change processes, notwithstanding driverless large-scale trials/deployments are not likely in the next five to seven years horizon. National Transport Commission is developing a nationally consistent approach to on-road enforcement for AVs.

Findings:

- The existing AV trial framework is found to be efficient and effective in mitigating and managing community expectations and road safety risks.
- Current AV trial regime may not be sustainable in three to four years horizon when mass produced AVs are likely to enter Australian market.
- While current process of consulting with the local law enforcement and first responders is adequate for short-term trials, they are not sufficient for large scale trials/deployments of driverless AVs.

Recommendations:

- Ensure AV national law, associated regulatory framework and national AV regulator are in place by 2026.
- Continue supporting National Transport Commission in developing a nationally consistent approach to on-road enforcement for AVs.

5 FINDINGS AND RECOMMENDATIONS

5.1 FINDINGS

General:

- Three use cases were identified as unique to Australia. These are 1) Road Trains/Long Vehicles, 2) Single Lane two-way rural roads, and 3) Wildlife, Kangaroos and Wallabies.
- Urban use cases are likely to be implemented much earlier than the use cases related to remote and regional environments, such as Single Lane two-way rural roads.
- Some scenarios, such as merging with short acceleration ramp and school zones, can easily be delivered if communication technologies (C-ITS messaging) are implemented.
- Several scenarios (such as flooded road) are not unique to Australia, however their exposure in Australia is much higher. In such scenarios, stopping the AV and seeking human intervention may be too disruptive.
- Very specific scenarios, such as hook turn in Victoria, has not been assessed in this study.

Road Trains/Long Vehicle Use Case:

- Off-the-shelf perception systems are not suitable for accurately detecting and classifying RT/LVs.
- Decision-making mechanisms must consider RT/LV length and dynamic characteristics.
- Machine learning techniques along with sensor fusion techniques can accurately detect and classify RT/LV.
- Rule based decision-making mechanisms utilising accurate high-definition maps of the road are likely to provide safe interaction between CAV and RT/LV.

Single Lane Two-Way Rural Roads Use Case:

- Accurate lateral positioning of the AV is difficult to achieve.
- Reliable detection of driveable space will be challenging.
- Dust may affect the sensor’s field of view.
- Decision-making mechanisms need to implement different set of rules depending upon the type of vehicle the AV is interacting with.

Australian Unique Wildlife Use Case:

- Kangaroo/Wallaby interaction data is very difficult to collect.

ZOE2 Trials:

- Succession of uphill and downhill road topography reduces AV’s field of view.
- Reflectors located inside the lane on uphill roads produce strong LIDAR reflection, increasing likelihood of a harsh braking event.
- Producing a naturalistic driving behaviour is difficult and needs to consider local road user behaviours. These behaviours could be aggressive or extra polite.
- Strategically locating sensors at high position may not be enough to improve sensor field of view.
- Overhung loads, such as ladder in the back of a utility vehicle, are difficult to accurately detect.

Regulatory Framework:

- The existing AV trial framework is found to be efficient and effective in mitigating and managing community expectations and road safety risks.
- Current AV trial regime may not be sustainable in three to four years horizon when mass produced AVs are likely to enter Australian market.
- While current process of consulting with the local law enforcement and first responders is adequate for short-term trials, they are not sufficient for large scale trials/deployments of driverless AVs.

5.2 RECOMMENDATIONS

General:

- Regulators should limit the Operational Design Domain (ODD) of the CAV if supporting technologies for safe operation (such as C-ITS messages, accurate high-definition maps) are not available.

Road Trains/Long Vehicle Use Case:

- ADS developers will need to ensure their perception systems are able to accurately detect and classify RT/LV including its length.
- ADS developers will need to ensure their decision-making mechanisms consider the length and dynamic characteristics of the RT/LV, especially during the overtaking manoeuvres.
- Regulators need to seek safety case from the ADSE (Automated Driving System Entity) demonstrating AV's safety remain '*so far as is reasonably practicable'* while interacting with RT/LV on Australian roads.

Single Lane Two-Way Rural Roads Use Case:

- Expand the study scope of future projects to prototype and confirm mitigation strategies for the scenario.

Australian Unique Wildlife Use Case:

- Expand the study scope of future projects to prototype and confirm mitigation strategies for the scenario.

ZOE2 Trials:

- ADS developers will need to;
  - strategically locate their sensors to optimise field of view,
  - implement robust sensor fusion based perception system taking inputs form varied sensors, such as LIDARs, Radars and Cameras,
  - demonstrate their ADS produces naturalistic driving behaviour in the Australian environment,
  - ensure, at minimum, IEEE 2846:2022 proposed assumptions are implemented,
  - implement modern detection techniques such as VIDAR in conjunction with sensor fusion techniques to provide high degree of detection assurance.

Regulatory Framework:

- Ensure AV national law, associated regulatory framework and national AV regulator are in place by 2026.
- Continue supporting National Transport Commission in developing a nationally consistent approach to on-road enforcement for AVs.