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Operations of Automated Heavy Vehicles in Remote and Regional Areas

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Abstract

This project identifies opportunities for future use of automated heavy vehicles in regional and remote areas of Australia and New Zealand, as well as any boundaries to prevent such use. The project aims to provide road managers and industry with direction for their development of facilities, procedures and regulations around the use of automated heavy vehicles.

The roles and responsibilities of road managers and government were defined in respect of the operation of the road network. The findings were based on the most suitable automated heavy vehicle operations in remote and regional areas, which were found to be automated highway driving and platooning.

An implementation roadmap was derived from the lessons learned covering the areas of technology, infrastructure (physical and digital requirements), regulation and opportunities in remote areas.

Keywords

Automated vehicles, heavy vehicle, road trains, platooning, auto pilot, digital infrastructure, regional and remote areas

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About Austroads

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- Roads Corporation Victoria
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- Main Roads Western Australia
- Department of Planning, Transport and Infrastructure South Australia
- Department of State Growth Tasmania
- Department of Infrastructure, Planning and Logistics Northern Territory
- Transport Canberra and City Services Directorate, Australian Capital Territory
- The Department of Infrastructure, Regional Development and Cities
- Australian Local Government Association
- New Zealand Transport Agency.

Summary

The aim of this Austroads project is to identify opportunities for future use of automated heavy vehicles, as well as mitigate any boundaries for such use. Focusing on regional and remote areas and the issues they present to vehicle operations, the work provides road managers and industry with direction for their development of public infrastructure and systems, procedures and regulations around the use of automated heavy vehicles[1].

This project is concerned with identifying and addressing the issues that will affect the roles and responsibilities of road managers and government in respect of the operation of the road network, due to the introduction of automation in heavy vehicles. The objectives of the project are to:

- provide governments with enough information to enable them to begin work on readying their networks for automated vehicles in remote areas
- enable the freight industry to work towards a degree of automation and explore the options provided by new technology
- identify opportunities for the use of automated vehicles in rural and remote areas
- inform governments on technical and legal issues so they can act in a timely manner to build or adjust infrastructure, and create legal frameworks, that are suitable for automated freight vehicles.

During the literature review and stakeholder consultation, there were two prominent use cases identified, namely: automated highway driving and platooning. Thus, this project focuses on exploring these two use cases, particularly the operational aspects. The following summarises the findings on these two use cases related to their operation in remote and regional areas.

Automated highway driving

- **Expected benefits.** Current automation technology for heavy vehicles is available up to Level 2, whereas Level 3 and above are still under development. The main motivation of the fleet operators to pick up an interest in automation is labour cost savings. Although this use case, particularly Level 3 and below, would practically still require a driver, there are other potential benefits associated with this use case. Firstly, the fleet is likely to be fitted with the latest safety equipment (as in the platooning case) that provides safety benefits. Additionally, Level 1 automation (driver assistance) has been shown to increase safety (whereas the claimed safety benefits of Level 2 and above need further investigation as they disengage the driver). Secondly, the driving workload is expected to be reduced, leading to a more pleasant work situation.
- **Physical requirements.** As with light vehicles, the technology would use various sensors and information to be able to safely navigate. Some of these relate to the use of sensors to position the vehicle within the lane, which would imply that clear lane markings are required. For Level 3 and above, clear signage would also be required. Additionally, technology developers may limit their system's ODD to a certain environment, such as multi-carriageway, multi-lane roads. Thus, this could also be a barrier in deploying this use case, or AHV in general.
- **Digital requirements.** HD maps for Level 3 and above may or may not be required depending on the technology. Precise positioning can be achieved by other means, such as by using dead reckoning (inertial navigation system) utilising information from various on-board units.

[1] As per the Heavy Vehicle National Law and Regulations, as a vehicle that has a GVM of more than 4.5 t.

- **Operational requirements.** Heavy vehicles, particularly in Australia have a significant modification market and restricted access. This would be expected to also extend to AHVs, which presumably are only allowed to operate on a subset of the road network compared to its manually-driven counterpart. International experts have suggested that the access issue will be handled by OEMs and fleet operators (without direct involvement of the government) as ODD limitations, which will be achieved through a programmed on-board mapping system. However, how the technology would handle the modification market is yet to be known. Finally, it is important to note that the international experts consulted indicate that the technology developers work under the assumption that the road operations stay the same (i.e. they are not expecting anything from the road operators).
- **Regulatory requirements.** As with light vehicles, the NTC work program can be extended to AHVs. Firstly, there are some road rules that may pose barriers to AHVs, as it is assumed that there is a human driver that controls the vehicle. Secondly, there needs to be a safety assurance system in place to ensure safe operations of the AHVs in the market, whereby the mandatory self-audit model is generally deemed to be reasonable. Thirdly, driver state monitoring may play a key role to ensure safety operation of AHVs Level 2 and above.

Platooning

In addition to the above, platooning requires some additional considerations as follows:

- **Technology.** Firstly, it is important to note that platooning involves two different vehicles which can be at two different SAE levels. Thus, the discussion about ‘platooning SAE level’ usually refers to the SAE level of the following trucks (except the V2V system, the lead truck essentially operates in the same manner as with a single vehicle). Secondly, the longitudinal control can either adopt a time-based or distance-based gap control. Thirdly, the lateral control is likely to be independent of the lead truck for safety reasons and robustness (i.e. the lateral control information is not transmitted via V2V between trucks), while a small ‘dithering’ can be introduced to address rutting issues. Finally, the newer generations of platooning systems are able to dynamically adjust the gaps to handle cut-ins and overtaking.
- **Expected benefits.** The main benefit of platooning is its fuel savings. However, mechanical coupling has already provided significant fuel saving benefits (although platooning will provide additional fuel saving). Also, the operational and productivity benefits of truck platooning in remote areas is yet to be compared with road trains. Having said that, as previously mentioned, platooning-abled trucks will be equipped with the latest safety technology, while the automation itself will reduce the workload of the drivers.
- **Physical requirements.** The biggest concerns on the impact of platooning on the physical infrastructure are rutting and bridge loading. However, experts suggest that, as mentioned before, the rutting issue can be addressed by adding a small ‘dither’ into the lateral control of truck platoons. Additionally, it has been suggested that platooning will not create additional problems on bridges, as the loading issue is caused by dynamic loading. Most platooning systems would typically use a 15 m gap for its commercial deployment, which seems to fall within bridge design specifications. If problems were expected to persist, the platooning system could use gaps that break up the periodic pattern of the axle loading. Since this is a complicated issue, an investigation into the currently permitted axle spacing compared with those likely to result from platooning would lead to a better understanding of the impacts on bridges.
- **Digital requirements.** With the exception of Peloton, there seems to be no additional digital infrastructure required for platooning. In the Peloton case, a platoon operation centre is used to manage the authorisation of platoons. This requires a periodic cellular communication. However, platooning systems developed by OEMs are unlikely to use such systems.
- **Operational requirements.** There are several operational considerations specific to platooning. Firstly, as with the single vehicle use case, the ODD for platooning will likely be handled by the OEMs through programmed on-board maps. However, it is important to note that the ODD is usually limited to multi-carriageway multi-lane roads, which does not suit typical regional streetscapes. Additionally, the government may provide guidelines and information to platooning system developers on particularly limiting roads. Secondly, trial results do not support that overtaking/cut-ins of platoons would be an issue. Cut-ins and overtaking are still regularly encountered at 15 m gaps (which is the expected operational gap for commercial deployment), and newer generation systems can dynamically adjust the gaps should cut-ins occur. Finally, handling such dynamic traffic situations would likely become the responsibility of the drivers.

- **Regulatory requirements.** An additional regulatory barrier to platooning is the following distance law, which may limit the gap up to 36 m in New Zealand and up to 60 m or 200 m for road trains in Australia. Further, if exemptions are given, visual cues (such as decals) to indicate platooning vehicles may be required for enforcement purposes and so that other road users can adjust their behaviours accordingly.

Implementation road map

The report identifies the need to establish an AHV implementation road map in Australia, with a specific road map for platooning technology. Firstly, the focus of the roadmap is not technology development, since that is mainly going to be led by OEMs. Rather, the focus of Australia should be to lead the regulatory and policy developments to support the deployment of AHVs. This is particularly important since the Australian condition is unique, where mechanical coupling of trailers is allowed and road conditions in regional areas are different than those in the USA and Europe. However, close collaboration with OEMs is still required to better understand the operational requirements of their technologies, particularly those in relation to enable interoperability in the future.

Some of the benefits of the road map are as follows. First, it will provide a clearer picture of the end goal to help determine the extent of trials to be performed (before being ready for commercialisation). Second, it will help in laying out the extent of regulatory and infrastructure supports required from the government. For instance, HD maps have emerged as a potential component, among many others, for the deployment of SAE Level 3 vehicles (automated highway driving). Finally, it will enable a clear differentiation of roles among key government entities to realise the various parts of the road map.

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1. Introduction

This project builds upon the previous three Austroads projects on automated vehicles (AV) (SS1867 Safety Benefits of Cooperative ITS and Automated Vehicles, BN2045 Assessment of Key Road Agency Actions to Support Automated Vehicles, and BR1982 Investigation of Potential Registration and Licensing Issues Due to the Introduction of Automated Vehicles), and it is timely, given the increasing number of AV deployments across the world, including in Australia and New Zealand, and the current requests from the industry to operate automated heavy vehicles (AHV) on public roads. The outputs of this project will help prepare road managers and industry by better understanding AHV use cases, particularly relating to operations in remote and regional areas, and the core functions required to support timely deployments.

The aim of this project is to identify opportunities for the future use of automated heavy vehicles, as well as mitigate any boundaries for such use. Focusing on regional and remote areas and the issues they present to vehicle operations, the work will provide road managers and industry with direction for their development of facilities, procedures and regulations around the use of automated heavy vehicles.

1.1 Background

Heavy vehicles perform a vital role in moving freight in Australia and New Zealand, both in urban areas as well as remote and regional areas. A large part of the freight task and economy, particularly in Australia is dependent on articulated heavy vehicles operating on long distance routes, for example between cities as well as between mines/farms and sea ports.

Long distance truck operation is a task which requires long durations of high-level human vigilance to ensure safety. The work is tiring and is associated with increased health risks for the drivers who perform it. As a result, despite the projected freight increase of up to 100% in the next 20 years, Carey (2016) suggested that Australia is faced with a problem of truck driver shortage, which needs to be more than doubled to meet the freight demand. Furthermore, when operating road trains in remote areas, the cost of providing drivers is exacerbated by the need to provide support services, including flights and accommodation.

Figure 1.1 shows a quad road train operated by QUBE for the transportation of iron ore in Western Australia. This type of combination is unique to the remote areas of Australia. This environment provides undeniable incentives to utilise automated technologies. The motivation for the current development has been a desire for reduced labour cost and increased safety and efficiency. The efficiency gains are particularly related to end-of-trip practices at loading and unloading facilities. The fleet operators are potentially ready to invest in further infrastructure and C-ITS development, on both public and private roads, to extend the range of the AHV program.

Figure 1.1: Quad road train operating in Western Australia

To date, trials of automated mine vehicles have occurred on privately managed roads, which was important in two respects. Firstly, there was very little likelihood of public vehicular traffic interacting with the mine's automated vehicles. Secondly, the geometry, surface condition, roadside features, signage and operational rules on the roads were controlled by the party responsible for operating the vehicles, or a party contracting the vehicle operator.

Extension of the AV program onto the public road network will change both conditions, with the state and local road managers becoming the entities responsible for the condition of the roads and the regulation of vehicles permitted to use them. The operators will need to demonstrate to the authorities that the AV experiments can be conducted safely within a mixed traffic environment and without disrupting the use of the network by other vehicle operators who work within the normal regulatory framework that governs the use of the roads. Currently, the two prominent use cases of automated heavy vehicles on public roads are single-vehicle automation and the platooning of AHVs through electronic coupling. (Note that the term 'driver assistive truck platooning' is more commonly used to describe platooning where the trailing truck(s) is(are) of SAE Level 1, to emphasise the driver involvement.)

Subsequently, this requires road managers to respond to requests and provide the opportunity for AHV operations. The use of vehicle automation has the potential to make the driving task easier and safer and should lead to opportunities for improved safety and productivity for a number of use cases, including long distance line haul routes for the transportation of minerals and produce to our terminals and ports for export.

1.2 Overview of AV Technology

1.2.1 Vehicle Automation Nomenclature

The following terms commonly used to describe automated vehicle operations require explanation to facilitate understanding of some of the topics discussed in this document.

Automated heavy vehicle (AHV) is a subset of the **automated vehicle (AV)** class and, as suggested by its name, refers to heavy vehicles (trucks) which have some degree of automation of the driving task. Heavy vehicles are defined in the law as motor vehicles exceeding 4.5 tonnes gross vehicle mass (GVM) or articulated trailer mass (ATM). In remote and regional areas, the heavy vehicle combination is typically a road train configuration comprising three or four trailers with a gross combination mass (GCM) above 100 tonnes. However, note that other combinations, such as general access semi-trailers, and rigid trucks may also be found operating in remote and regional areas. AVs are vehicles which contain some degree of automation but are not necessarily at Level 5 automation.

Dynamic driving task (DDT) is the term used to describe the operational and tactical tasks (but not the strategic tasks) required to operate a vehicle's controls while navigating it along the required path. The task is usually performed by a human driver, and the aim of automation is to pass all components of the DDT to the vehicle itself. The automation hierarchy described in Table 1.1 below is concerned with the extent to which the vehicle takes over some components of the DDT.

Operational design domain (ODD). The vehicle's automation features operate within the ODD, which sets limits under which conditions the automation can function. The ODD may be vehicle-, spatially-, temporally-, or environmentally-imposed.

Automated driving system (ADS) is a system that is capable of performing components of DDT on a sustained basis (regardless of ODD limitation). Note that this is different compared to the SAE definition of ADS, which refers to a system that can perform the entire DDT. The term Advanced Driver Assist System (ADAS) is commonly used to describe functions such as assisted parallel parking, lane keep assist and auto-pilot that are available on modern passenger cars and heavy vehicles. To avoid confusion, this report will only use the term ADS.

DDT fall-back: In the case of a DDT performance-relevant system failure, this describes the response by the user or an ADS to take over and perform the DDT or to achieve a minimal risk condition.

The Society of Automotive Engineers (SAE) International (2016) has published a scale of vehicle automation ability, using six levels of automation to describe the degree to which a vehicle is able to perform various control functions by itself. The scale runs from Level 0, involving zero automation, to Level 5, where a vehicle controls itself and has no human control inputs. Table 1.1 summarises the levels of automation.

Table 1.1: Definitions of the levels of automated driving

Level	Automation	Other information
0	No automation of driving tasks	The vehicle may have active safety systems.
1	Autonomy of 1 primary control function	The vehicle is able to perform either longitudinal or lateral control but not both, for example either Adaptive Cruise Control (ACC) or Lane-Keep Assist (LKA).
2	Autonomy of 2+ primary control functions	The vehicle performs both the longitudinal and lateral control. Human driver must actively monitor the road situation and intervene as necessary to maintain safety.
3	Full automation on specified ODDs	The vehicle performs all DDTs in some situations, for example highway auto-pilot, parking. Driver must be available to take over.
4	Full automation with DDT fall-back	The vehicle performs all DDTs with fall-back capability. The driver has no responsibility to take control of driving within the ODD.
5	Full automation only	The ODD is unconstrained.

1.2.2 Available Automation Technology

As per SAE definition, DDT is comprised of several components.

Automation of the DDT requires a vehicle to be able to safely control safety-critical systems including the steering, braking and acceleration of the vehicle. At higher levels of automation, the vehicle must also be able to safely detect objects and the environment around the vehicle, and dynamically respond without a human driver monitoring the environment.

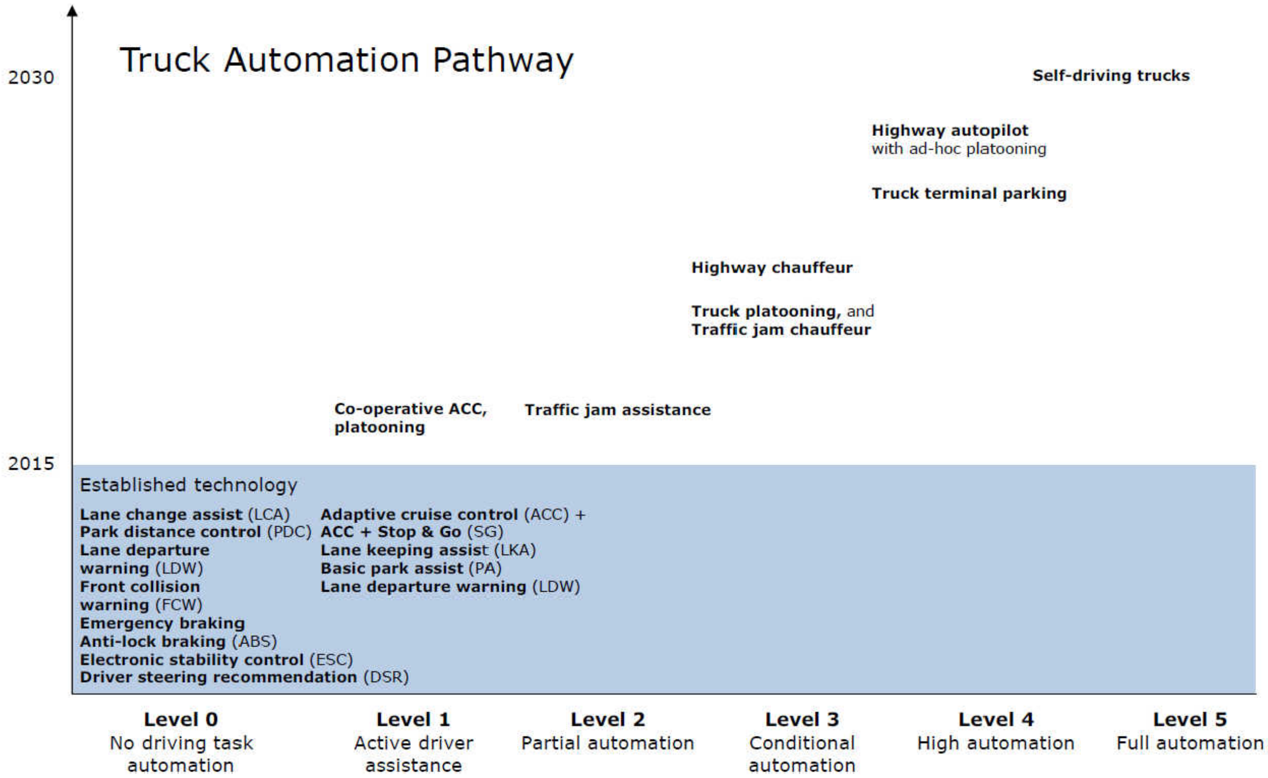
To achieve this, a common pathway manufacturers are adopting is through the integration of systems that are currently featured in some light and heavy vehicles including:

- adaptive cruise control (ACC)
- electronic braking systems (EBS)
- automated emergency braking (AEB)
- roll stability program (RSP).

Achieving higher levels of automation requires systems, software, validation and testing beyond what is available in current market vehicles.

In the case of trailer manufacturers, many of the advanced technologies such as EBS and RSP are fitted as after-market options, often by specialist suppliers. The compatibility of these systems with the systems fitted to a prime mover needs to be considered to ensure that full functionality on the trailers is achieved. It is expected that the initial AHV trials will be conducted with modern prime movers equipped with these technologies. During the consultation process with transport operators and prime mover original equipment manufacturers OEMs (presented in Section 3), it was explained that they will be able to implement existing automated functions and potentially modify them as part of a trial which would allow the prime movers to operate with a higher level of autonomy. An example of the pathway to truck automation and the associated functionality is shown in Figure 1.2.

Figure 1.2: AHV deployment path by International Transport Forum (ITF)



Source: Alonso Raposo et al. (2017).

The two components of DDTs that are most relevant to line haul deliveries are longitudinal and lateral control, which are controlled by ACC and lane centring respectively.

According to SAE taxonomy, the conventional cruise control is not considered performing the longitudinal control on a sustained basis, since it does not receive any external input (it only reacts to the deviation of the vehicle speed from the set speed). A vehicle must have ACC at the very least to be able to 'automate' the longitudinal control. An ACC system can detect any vehicle ahead and adjust the vehicle speed accordingly to avoid rear-end collision. The driver still needs to select the set speed and either the following distance gap or time gap. The commercially available ACC may operate only in limited traffic conditions, such as high speed (highway autopilot) or low speed (traffic jam assist). An enhanced version of ACC is Cooperative ACC (CACC), which utilises a V2V (vehicle to vehicle) communication system to coordinate the acceleration and deceleration of the following vehicle. It is usually employed to form platoons of vehicles that follow each other at a constant distance/time gap. A standard and test procedures for CACC technology have been published by International Organization for Standardization (ISO) (2017). Note that the term CACC and truck platooning have been differentiated in the literature. Although both refer to electronic coupling of vehicles, there are some operational differences between the two technologies, which is covered in more detail in Section 2.2.2.

The LKA technology may be placed into two categories based on the control strategy. The first category steers back the vehicle into the lane when the vehicle starts to drive onto the lane marking. However, this will result in a zig-zag driving pattern when the driver does not intervene. Another strategy is also often referred to as the lane centring assist (LCA), which tries to keep the vehicle at the centre of the lane. In its current state, this technology needs a clear lane marking that is detectable by the vehicle sensors.

For automated driving to be classified as SAE Level 3, it needs to be able to perform all aspects of DDT in addition to lateral and longitudinal control, but it does not need to have full fall-back capability to be able to achieve a minimal risk condition without driver intervention. At this stage, there is no commercially-available vehicle that can be categorised as Level 3.

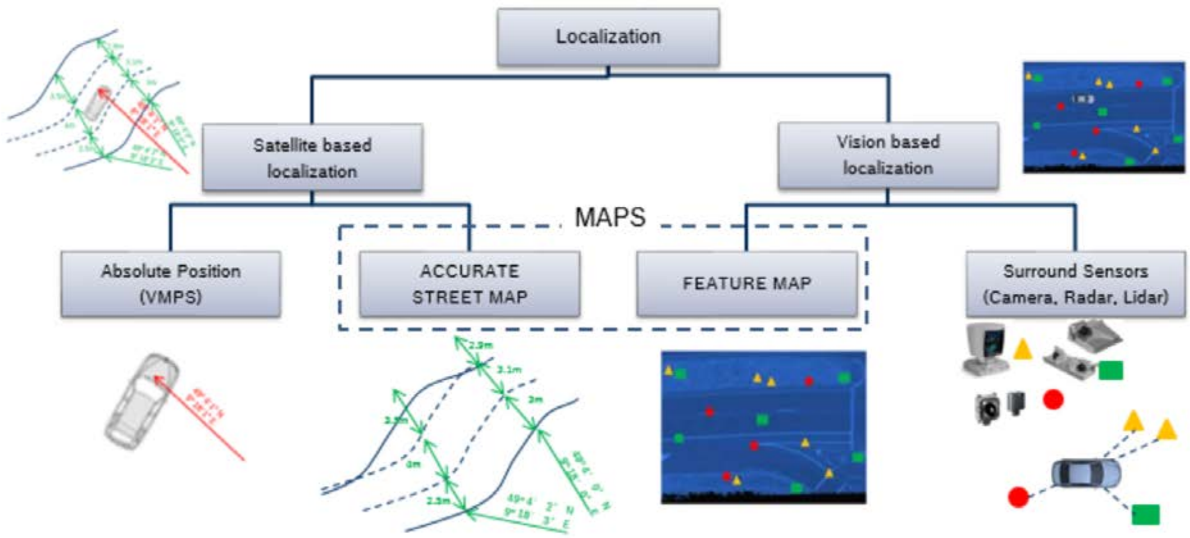
1.2.3 Positioning

This section draws from another Austroads report Assessment of Key Road Operator Actions to Support Automated Vehicles (Austroads 2017).

The ability for an AV to know its absolute position on the ground and its relative position to physical attributes within the road environment will be critical to its ability to safely automate the dynamic driving task. AVs will use a range of different on-board sensors to determine its relative position. Different vehicles may use different sensors and may take different approaches to determining a vehicle's position. Due to the complexity of the nature of the task, no single sensor can perform all tasks required for a vehicle to 'see' and interact with its environment and safely navigate the road. Some road environments will be complex, such as urban roads that involve traffic lights, pedestrians, and varying road rules. For an AV to successfully drive on the road it must have a sensor system capable of navigating through this environment, or having 'localisation'.

Figure 1.3 outlines the Bosch model for localisation and provides a good basis for appreciating the localisation challenge. Under this model a combination of many data sources is brought together to build a model of the road environment and facilitate control within that environment.

Figure 1.3: Sensor fusion and localisation



Source: Austroads (2017).

Key elements to the localisation process include the following:

- **Development of the digital map database to allow the vehicle to navigate the road network:** A combination of accurate street maps with accurate feature maps will be required by most AVs. These maps must be current and may require some management. A current challenge of road operators is to have roads opened digitally and physically at the same time, e.g. to have asset/map bases updated for 'day 1' of a new road. For those AVs that require digital map data, the data attributes will likely be updated and accessible via a cloud service. Road operators are expected to have a role in forming or contributing to these databases.
- **Localisation within the digital map environment:** For most this will be through Global Navigation Satellite System (GNSS), with some supplementing this with terrestrial positioning services. With mass market AV, it appears that emerging vehicle positioning requirements are being met by a space-based augmentation system (SBAS).
- **Sensing of the local road environment to add physical features to the digital map environment:** Cameras, LIDAR, radar, and ultrasound devices are utilised to log features within the local road environment.

- **Adaptation and response to the road environment based on the live road environment:** Simultaneous location and mapping (SLAM) technology allows for the construction or updating of a map of an unknown environment while simultaneously keeping the vehicle within the map.

Requirements for absolute positioning

In the short to midterm it is likely that the majority of AVs will be able to operate sufficiently well by utilising GNSS, which is readily available as a primary method of absolute positioning; as noted earlier, AVs will primarily be reliant upon on-board sensors for relative positioning. This will be combined with vehicle mounted sensors to help determine relative positioning and will potentially allow vehicles to operate for periods of time without GNSS coverage where it is either unavailable or not sufficiently accurate for the driving situation.

There is a wide range of industries (including automotive) reliant on absolute positioning that will have stringent requirements for accuracy, coverage and integrity of positioning. Many AV developments internationally are using an SBAS-enabled GNSS receiver to meet their absolute positioning requirements. The SBAS augmentation signals are freely available in some jurisdictions, and while the signal formats are internationally consistent, the augmentation signals are unique to different international regions.

In contrast to many regions in the northern hemisphere, Australia and New Zealand do not currently have an existing SBAS service freely available for use. This lack of free access to an SBAS could potentially act as a barrier to some AVs being introduced to our market or to some cases/applications being supported. Vehicles developed for the major markets of Europe, Asia, or the Americas will likely be developed to utilise the positioning technologies available in those regions. For example, Europe has the Geostationary Navigation Overlay Service (EGNOS) and North America has the Wide Area Augmentation System (WAAS).

In Australia and New Zealand, in the absence of a compatible SBAS service, there may be a requirement for hybridised systems using existing GNSS and ground-based positioning technology. These may require different hardware to be fitted unique to these markets, which could present commercial and manufacturing barriers that may not be feasible for mass market production vehicles.

In addition to this limitation there are also a number of other specific positioning challenges which road transport applications will need to overcome. Examples of these include:

- tunnels
- urban canyoning and multilevel car parks
- spoofing
- tampering or jamming signals
- solar flares
- GNSS vulnerability to outages.

There are a number of possible technical solutions that could be used to implement positioning solutions to overcome the problems listed above. Some solutions utilise additional terrestrial-based systems to supplement, enhance or replace GNSS positioning. Solutions such as differential GPS (D-GPS), real-time kinematic (RTK) systems, and precise point positioning (PPP) are examples of these. Key challenges in adopting these other potential solutions is that it may not be feasible for vehicles sold in Australia and New Zealand to have equipment fitted (e.g. GNSS receiver) that is unique to these markets, and commercial positioning services that have an ongoing subscription fee may not be supported by vehicle manufacturers or the market.

Absolute positioning is also an important requirement for many C-ITS applications. A summary of potential positioning technologies to support C-ITS is shown in Table 1.2 which was developed as part of the Austroads study Vehicle Positioning for C-ITS in Australia (Austroads 2013), which is also highly relevant to the consideration of AV needs.

Table 1.2: Vehicle positioning for C-ITS in Australia

Hybrid positioning systems	Media	Standards	V2X	Comments
Low-end GNSS receiver + low end on-board sensors	5.9 GHz DSRC GNSS broadcast signals	SAE2735, IEEE 802.11p, WAVE IEEE 1609, GPS navigation messages	Satellite to Vehicle V2V	Available anywhere in Australia. This is the easiest solution available for C-ITS roll-out now however it has limitations associated with not having SBAS coverage for Australia.
Low-end GNSS/SBAS/Locata receiver + low-end on-board sensors	L-band satellite communication; GNSS and SBAS broadcast signals, 5.9 GHz DSRC	SBAS messages, SAE2735, IEEE 802.11p, WAVE IEEE 1609	Satellite to vehicle V2V	SBAS signals are not available in Australia. Development efforts are required to make this solution available. The solution avoids user operational cost due to cellular communications.
Low-end GNSS/Locata receiver + low-end on-board sensors + mobile data link	Cellular network: 2G, 2.5G, 3G and 4G, 5.9 GHz DSRC	SBAS, SAE2735, IEEE 802.11p, WAVE IEEE 1609, NTRIP	V2I, I2V, V2V	Available in the CORS and 3G14-G overlap areas. Implementation can start any time.
Dual-frequency GNSS + high-end on-board sensors+ mobile data link	Cellular network: 2G, 2.5G, 3G and 4G, 5.9 GHz DSRC	RTCM 104 3.0, SAE2735, IEEE 802.11p, WAVE IEEE 1609, NTRIP	V2I, I2V, V2V	Available in the CORS and 3G overlap areas. Implementation can start any time.
Dual-frequency GNSS/Locata receivers + mobile data link	Cellular network: 2G, 2.5G, 3G and 4G, 5.9 GHz DSRC	RTCM 104 3.0 SAE2735, IEEE 802.11p, WAVE IEEE 1609, NTRIP	I2V, V2I, V2V	Available in the CORS and 3G overlap areas. Implementation can start any time.

Source: Austroads (2013).

In unique circumstances, such as tunnels, there may be a requirement to provide dedicated positioning infrastructure. There has been some work undertaken internationally exploring potential solutions, including with GNSS repeaters and Bluetooth beacons. Multi-path issues appear common due to the closed environment of tunnels. At this stage it appears unclear what in-tunnel positioning requirements might be for AVs.

In the 2018 Budget, the Australian Government announced $224.9 million to make reliable positioning data accurate to 10 centimetres available across Australia. Areas with mobile coverage will have access to positioning data accurate to 3 centimetres. Of the $224.9 million, $160.9 million will be used to fund an SBAS for Australia. The remaining $64 million will be used to establish a national ground station network, improve coordination across government and the private sector, and ensure Australian industry has access to world-leading software tools for positioning.

1.2.4 Concern on Mode Transition

One of the safety concerns with automation is the transition of driving mode from automated to manual, particularly Level 3 and below where the vehicle is incapable of DDT fall-back. This means that the driver needs to be ready to intervene at all times. It has been noted by an expert that, as a result, there is very little activity for Level 3 vehicles commercially. The industry focus is likely to be initially on Level 1 and Level 2, leading to Level 4.

A study conducted by Dixit, Chand and Nair (2016) discovered a correlation between the driver's trust level and the reaction time to a request to intervene. As the drivers become more trusting (indicated by an increase in the vehicle distance travelled), the reaction time increases and the cognitive load on the driver is minimal. Additionally, a less complex traffic situation, such as highway/motorway, would lead to a longer reaction time. Note that this finding aligns with the opinion of Bainbridge (1983), who suggested that automation would put the driver out of practice and, consequently, would reduce the driver's capability to appropriately intervene on time when requested.

In addition to reaction times, the driver also needs time to be fully aware of the surrounding traffic conditions. Lu, Coster and de Winter (2017) found that drivers required between 7–12 seconds to be fully aware (from completely unaware) of spatial patterns of the traffic. Furthermore, in order to be fully aware of the relative speed of the surrounding vehicles compared to the driven vehicle, drivers may need longer than 20 seconds. As a solution, Louw and Merat (2017) suggest that, during automation, it is better to direct the driver's gaze towards the centre of the road, such as by using heads up display instead of dashboard human machine interface (HMI).

The importance of this safety concern will be more pronounced in the discussion of the AHV use cases in Section 2.2.

1.3 Current Regulatory Environment

The National Heavy Vehicle Regulator (NHVR) administers the Heavy Vehicle National Law (HVNL), which is a single set of laws applicable to heavy vehicles over 4.5 tonnes GVM and performs a range of regulatory services including access permit applications, the national driver word diary, including the management for fatigue and driving hours, and vehicle standards. All these services are applicable to the heavy vehicle configurations proposed for automated operations by the transport operators during the industry consultation phase of this project. It should be noted that all the states and territories except for Western Australia and the Northern Territory have adopted the HVNL. Access to the road network is the responsibility of road managers. Network access is granted to vehicles based on a number of considerations including their mass, dimensions, loading, configuration and performance, which ultimately influences their suitability to operate on parts of the road network.

When a permit application is submitted to the NHVR, it is processed based on the vehicle's compliance to the regulations and standards; following this step, an access request is made to the appropriate road manager. A heavy vehicle operating with a level of automation will not alter its compliance i.e. the vehicle's mass, dimensions and mechanical design remains unchanged; therefore, the role of the NHVR in this respect is not expected to change. However, the vehicle's operation may change, and the basis upon which access was originally granted to the heavy vehicles (with no automation) may have changed and require reassessment. The assessment of the road network's suitability to accommodate automated vehicles, and ultimately, the access decision, is the responsibility of the road manager. For example, a 53.5 m long road train may be granted access to the road network based on the ability of other vehicles to overtake safely, when operating in a platoon if the decision was based on the vehicle's length being fixed at 53.5 m. But if two of these 53.5 m long vehicles created a two vehicle platoon, the length would be over 100 m and this safety assumption would no longer be valid. In this example, it would be the responsibility of the applicant to demonstrate that the platooning vehicles perform equivalent to the 53.5 m vehicle, potentially by disengaging from the platoon when overtaking is required; alternatively, the road manager must reassess the suitability of the network.

Road managers have the right to apply conditions when granting access to restricted access vehicles, and it is likely that similar conditions will be applied to automated operations. A summary of how access conditions relate to and are applied to restricted access vehicles is summarised below.

The HVNL defines access conditions in three categories: vehicle, road and travel. The vehicle conditions are primarily the responsibility of the NHVR whilst the travel and road conditions are primarily the responsibility of the road manager. This is based on the roles and responsibilities of each organisation. Generally, vehicle conditions should include the following:

- how the vehicle should be configured (e.g. trailer type)

- general requirements to mitigate risks subject to a particular mass or dimension
- installation and use of certain components (including safety features or other equipment)
- limiting the vehicle to a particular speed.

Table 1.3 lists the considerations for managing risk of restricted access vehicles. The considerations for the NVHR that relate to the vehicle's physical characteristics (i.e. mass and dimensions) are not expected to change with the implementation of AHVs, but those relating to the vehicle's performance may.

Table 1.3: Considerations for managing risks of restricted access vehicles

NHVR (vehicle considerations)	Road manager (travel and road considerations)
Size and mass of the vehicle	Vehicle's ability to interact with surrounding traffic
Security of couplings	Vehicle's ability to interact with the infrastructure and road
Distribution of mass	Suitability of the dimensions (length and width) of the road
Dynamic stability and tracking characteristics	Location of infrastructure on or near the road
Acceleration and braking characteristics	Traffic conditions
Manoeuvrability	Use of properties near the road
Visibility to other road user	Sight distance for other road users
Suitability of the vehicle to the task	Clearance zones for the road
Load restraint	Results of road safety audits
Rollover risk	Suitability of the road for transport of dangerous goods

The list of considerations is broad and requires extensive knowledge of heavy vehicles, roads and infrastructure. Road conditions are intended to minimise risks associated with road infrastructure, the community and public safety. As a guide, the NHVR provides the following examples of road conditions:

- do not use particular bridges or sections of the otherwise-approved route
- only carry particular loads
- be limited to a particular speed
- travel at a speed under the posted speed limit
- operate in a specified position on the road, e.g. travel in certain lanes may be restricted
- require the operator to participate in an intelligent access program.

This process is structured and is based on a well-established understanding of heavy vehicle performance and infrastructure capacity. The performance of automated operations and the interaction with other road users and infrastructure is less understood. Therefore, there is likely to be a reliance on transport operators to provide evidence of risk management, performance and system functionality.

Compliance and enforcement of chain of responsibility (COR) and fatigue management laws are services offered by the NHVR. Regarding COR, the NHVR recommends a safety management system (SMS). Transport operators are familiar with this and an SMS was suggested during industry consultation as a means of demonstrating compliance. The SMS currently in use by transport operators would need to be updated to include risks associated with automated operations. The driving tasks of Level 1 and Level 2 operations are not expected to differ from non-automated driving; therefore, the fatigue management laws will apply as they do now. It is possible that benefits arising from reduced driving tasks and attention during Level 3 and Level 4 operations could be reflected in exemptions from fatigue management laws, but this is not relevant to the operations proposed by industry for initial trials.

1.4 Scope

The technical and operational aspects of the various components of automated vehicles are not under examination in this project. Rather than developing or testing new vehicle capabilities, this project is concerned with identifying and addressing the issues that will affect the roles and responsibilities of road managers and government in respect of the operation of the road network, due to the introduction of automation in heavy vehicles.

The objectives of the project are to:

- provide governments with enough information to enable them to begin work on readying their networks for automated vehicles in remote areas
- enable the freight industry to work towards a degree of automation and explore the options provided by new technology
- identify ways in which the use of automated freight vehicles would help to create opportunity in rural and remote areas
- inform governments on technical and legal issues so that they can act in a timely manner to build or adjust infrastructure, and create legal frameworks, that are suitable for automated freight vehicles.

Aligned with these objectives, the scope of the project includes:

- understanding the ability of remote and regional road infrastructure to handle AHVs
- interactions of AHVs with other road users
- the impacts of AHVs to infrastructure
- identification and prioritisation of deployment opportunities of AHV operations.

Regulatory recommendation is outside the scope of this project. Yet, the report still summarises current policies affecting AHV trials and identifies potential regulatory barriers for large-scale commercial deployment of AHVs, both automated operation of single-vehicle and platooning (multi-vehicle automation).

1.5 Report Structure

This report is structured as follows.

- **Section 2: Literature review** – This section provides a review of the current literature relevant to AHVs in deployment. The review considers: the opportunities in remote and regional areas based on current technologies, the infrastructure and regulatory requirements, the key success metrics of AHV deployments, and the impact and risk management of the identified use cases.
- **Section 3: Impacts and opportunities** – This section presents the results of industry engagement that were aimed to better understand their needs. Two fleet operators and an Austroads representative were consulted. The use case of interest to the industry representatives was analysed and compared against the requirements, risks, impact, and relevant regulations as identified from the literature review.
- **Section 4: Industry expert consultation –** As part of the stakeholder consultation, discussions were held with industry experts, and this section presents the outcome of the two webinars held as part of the discussions by summarising the key highlights of the discussion.
- **Section 5: Conclusions –** This section concludes the report by summarising the learnings and proposing an implementation roadmap of the two use cases relevant to Australian remote and regional areas.

2. Literature Review

The review was undertaken to gain an improved understanding of both international and local literature on AHVs for readiness to run AHV trials in Australia and to measure their success. The review identified the following important aspects of running trials of AHVs:

- AHV opportunities in remote and regional areas
- infrastructure requirements
- regulatory requirements
- key success metrics
- impact and risk management.

A summary of key documents from the literature review is provided in Section 2.1. A detailed review for each of the topics listed above is provided in Sections 2.3–2.6.

2.1 Summary of Key Documents

The following six documents were identified as key publications for understanding the requirements of AV operations. Each has been summarised below:

1. *Assessment of Key Road Operator Actions to Support Automated Vehicles AP-R543-17* (Austroads 2017)

- This report provides high-level guidance for road agencies and operators to support and optimise the introduction of AVs operating on public and private road networks (including urban and rural areas). The report captures key issues in three broad categories: physical infrastructure, digital infrastructure, and road operations.
- Several physical infrastructure aspects that need consideration are as follows. Firstly, road and infrastructure design might need to be adapted depending on the considered use cases. Similarly, road pavements and structures might need some adjustments to accommodate use cases such as heavy vehicle platooning. The platooning of heavy vehicles may lead to several impacts: concerns on the change in load dynamics and load volumes[2]; tolling technology to identify each vehicle in the platoon; and operational considerations such as overtaking, platooning near on-/off-ramps, and designated lanes. Furthermore, consistency in design and maintenance of road signs and lines, as well as consistency in road works traffic management are required. Finally, the idea of certification of roads as 'AV suitable' was mentioned.
- The lack of important digital infrastructure in Australia and New Zealand has been identified in this report. In particular, both Australia and New Zealand have relatively low geographical coverage of cellular networks, no access to an SBAS system for absolute positioning, and the lack of availability (and accessibility) of digital maps of road networks and platform for data exchange in Australian and New Zealand.
- Finally, road operation considerations include: adapting the approach to network management; updating a range of standards, guidelines, and regulations; and standardisation of road works management.

[2] The concern regarding loading changes due to platooning needs further investigation, as experts suggest that it is no different to the loading of road trains.

2. *Guidelines for Trials of Automated Vehicles in Australia* (National Transport Commission 2017e)

- These guidelines cover the key aspects to be considered when running trials of AVs in Australia. These aspects are: trial management, insurance, safety management plans, data and information management, and implementation. Firstly, the key trial management criteria include a detailed plan of the trial, description of technology, and public and stakeholder management. The guidelines indicate that appropriate insurance for all affected parties needs to be obtained for the trials. Furthermore, the safety management plan needs to follow a set of key safety criteria, while data transparency regarding incidents during the trial is also needed. Finally, several implementation considerations, such as cross-border trials, were identified. These guidelines are covered in more detail in Table 2.2 in Section 2.4.

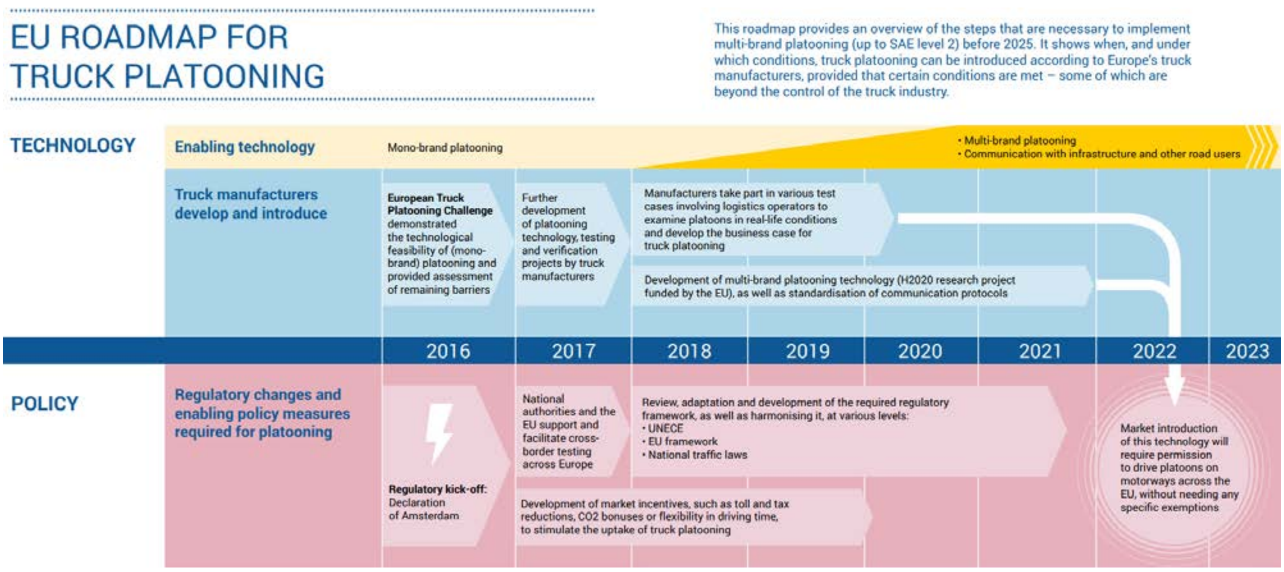
3. *Automated Vehicles: Are we Ready?* (Somers & Weeratunga 2015)

- This report investigated the potential implications of the introduction and wider use of AVs on Western Australian roads, which will inform Main Roads' strategic decision. Firstly, this report covers the impacts of AV operations. There are a wide range of potential impacts being discussed, such as safety, productivity, and environmental benefits. Furthermore, the report identifies emerging issues with AVs. In particular, concerns have been raised regarding the maturity of technology, human factors, liability and regulation, privacy, (digital) security, public acceptance and accurate positioning. Then, the report summarises the current state of play both locally and internationally, which generally attempts to address these emerging issues. Finally, the report discusses the potential implications for MRWA in light of the estimated AV adoption rates and timelines. The timeline consists of two periods, namely transition and full saturation. During the transition period, MRWA is encouraged to be proactive in preparing for AV operations. Several actions that can be taken to prepare are: road side equipment (RSE) installation[3], road signs and markings standardisation, standardised digital data format for vehicle-to-everything (V2X), provision of data such as high definition digital maps[4], and potentially dedicated infrastructure for AVs (which could be dedicated only for a certain period of time). When AV penetration has reached its full saturation, transport models and management are likely to have changed drastically compared to the current state of play. Thus, MRWA is encouraged to take initiative and be a leader in accelerating these changes such that WA will be ready when the changes occur.

4. *EU Roadmap for Truck Platooning* (ACEA 2017)

- The European Automobile Manufacturers Association (ACEA) provides a roadmap for truck platooning. The road map shown in Figure 2.1 addresses the deployment challenges of technology and policy.

Figure 2.1: EU road map for truck platooning



Source: ACEA (2017).

[3] However, an expert suggests that no commercial developers are asking for RSE.
[4] An expert has suggested that this will be handled by private sectors.

5. ***European Truck Platooning Challenge 2016: Creating Next Generation Mobility: Lessons Learnt* (Alkim et al. 2016)**

- The booklet reports the lessons learned from the European Truck Platooning Challenge (ETPC) performed in Europe in 2016. The booklet discusses a wide range of operational aspects of a trial. The first two parts cover the regulatory approval of the trial. The trial needs to obtain operational permit from all the countries that the route is in, as well as obtaining a road rules exemption through a detailed safety management plan. The next part explores the human factors aspect by summarising the truck driver experience during the trial. In general, due to ETPC's rules (such as a lower than usual speed limit), the drivers, who are already familiar with the ADAS being trialled, were challenged by complex traffic scenarios and, thus, controlling the vehicle more conservatively than what is necessary, which is a concern that may or may not translate to commercial deployment. Finally, the booklet concludes the report by discussing the view of the stakeholders and the considerations to ensure safe transition from trials to real-life commercial deployment of platooning technology.

6. ***Operational Concepts for Truck Cooperative Adaptive Cruise Control (CACC) Maneuvers* (Nowakowski et al. 2016)**

- This paper outlines in detail the manoeuvres and operational concepts of Level 1 truck platooning based on CACC. Note that Level 1 truck platooning is the case where the following vehicle is automated in terms of its longitudinal control only, whereas Level 2 truck platooning is the case where the following vehicle is automated both in longitudinal and lateral control (as per SAE taxonomy). Firstly, this paper clarifies the difference between Level 1 (CACC) truck platooning and Level 2 truck platooning. The former employs constant-time-gap strategy and, as a result, is more flexible in its procedures and control. The latter uses constant-distance-gap strategy and, consequently, is more sensitive to certain manoeuvres (such as sudden braking) and requires more formal procedures. This implies that CACC truck platooning is more flexible in its coordination, in a sense that a truck may join and leave the platoon in an ad-hoc manner.
- This paper then discusses the operational concepts of CACC truck platooning. Firstly, the coordination may take place locally, globally/centrally, or in an ad-hoc manner. Secondly, it points out the importance of truck sequencing by proposing that the truck with the worst braking performance should be the lead to prevent rear-end crashes within the platoon (such as during sudden braking). Thirdly, the paper indicates that the length of a platoon is limited by communication equipment (Dedicated Short-Range Communications, DSRC) capability to approximately eight trucks, yet it is practically limited to two or three trucks (for safety consideration to other road users). Finally, the paper outlines activity diagrams for the joining manoeuvres, steady state cruising, and splitting manoeuvres. The activity diagrams describe the information exchange, role of the drivers, and the role of the systems along the timeline during the manoeuvres.

2.2 AHV Opportunities in Remote and Regional Areas

AVs have brought up many potential use cases in general. The two use cases most relevant to remote and regional areas are:

- automated highway driving (at various levels)
- platooning.

These two use cases are discussed in further detail in Sections 2.2.1 and 2.2.2.

An important technology that complements AHV operation is driver state monitoring, which assists in monitoring the driver's attention and managing their fatigue. The discussion of the use cases will point out how this technology will play a role in assuring the safe operations of AHVs. The state-of-the-art driver state monitoring technology will also be discussed in Section 2.2.3.

Finally, the AHV deployment path is presented in Section 2.2.4 (ERTRAC 2015; Alonso Raposo et al. 2017).

2.2.1 Automated Highway Driving

The most straightforward use case of AHVs is automated highway driving. In this case, the automated functionality may range from Level 1 to Level 4. This report will focus only on Level 1–3 automation. However, it is noteworthy that several OEMs, such as Tesla and Embark, are working on Level 4 heavy vehicles.

At Level 1, the vehicle is either equipped with ACC or LKA, but not both. For Level 2 automation, the vehicle has both ACC and LKA. These two technologies are already widely available commercially. At Level 3, the vehicle can perform all aspects of DDTs, yet without any DDT fall-back capability.

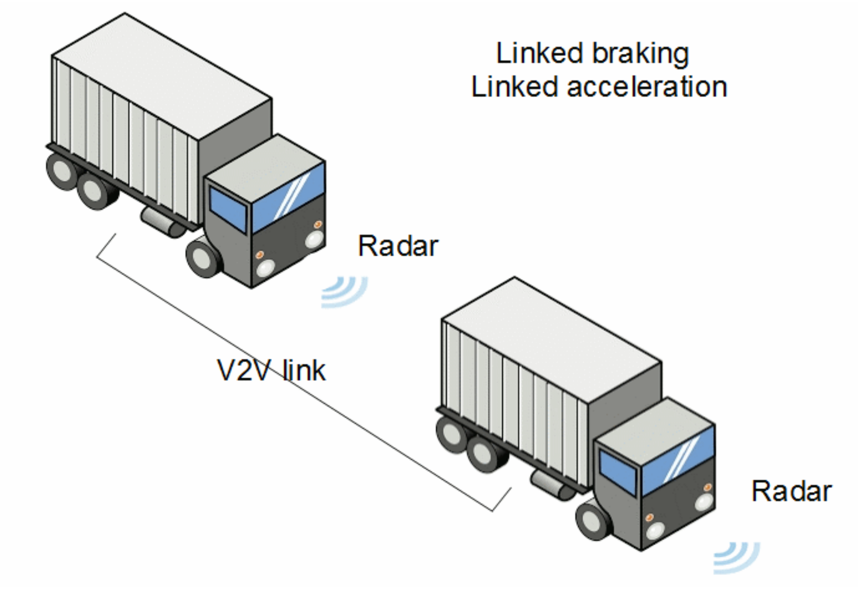
Because of the DDT fall-back limitation of Level 1–3, the driver needs to be ready to intervene on a request to handover. In fact, some parts of the ADS may fail to perform. As a result, many car manufacturers emphasise that the driver is still responsible for the control of the vehicle even though the auto-pilot function is engaged.

As previously discussed, there are some concerns raised regarding the driver's reaction time to the request to intervene. As the driver becomes more trusting of the AV technology, the reaction time increases. This highlights the importance of the driver state monitoring technology to ensure safe deployment of AHVs, as suggested by the Tesla's Auto-pilot crash report (National Transportation Safety Board 2017). The technology can be used to monitor the driver's attention and alertness to ensure that the driver is ready to intervene at any time. An example of such technology is GM Super Cruise[5].

2.2.2 Platooning

In a more general sense, platooning is an act of grouping vehicles to form a convoy, such as those that are naturally formed through coordinated intersection signal control, also known as *green wave* (Grace & Potts 1964; Morgan & Little 1964; Robertson & Bretherton 1991; Brockfeld et al. 2001). More specifically, in the automated vehicle field, the vehicles in the convoy follow each other with smaller headways than what is normally permitted. This can be achieved due to the ADS being able to react faster to sudden braking compared to human drivers. More importantly, communication among the vehicles in the platoon provides the ability to coordinate the acceleration and deceleration of the vehicles, which plays an important role in maintaining the stability of the headway within the 'string' of vehicles, referred to as the 'string stability' (Liu et al. 2001; Seiler, Pant & Hedrick 2004; Middleton & Braslavsky 2010). The fundamental elements of platooning including the communication component is illustrated in Figure 2.2.

Figure 2.2: Fundamental elements of platooning



[5] https://www.cadillac.com/world-of-cadillac/innovation/super-cruise

Truck platooning systems

The key aspect of a narrow spacing platooning system is V2V communication. It has been pointed out that communication delay will induce string instability (Liu et al. 2001), which means communication systems with low latency is essential. To date, this has been demonstrated through the use of Dedicated Short-Range Communication (DSRC) units operating at 5.9 GHz bandwidth. Similarly, the future 5G C-V2X using vehicle-to-vehicle connection would potentially be able to provide connection with sufficiently low latency to enable truck platooning.

Platoon operation centre

Peloton, a platooning system provider, only allows the formation of a platoon on certain ODDs. As such, there needs to be a central operation centre to coordinate and authorise the platoon formation. This implies that a cellular connectivity is needed for regular communication with the operation centre. The regular communication may not necessarily be constant and can only be performed periodically (for example every 15 minutes). However, this model is not general as truck OEMs will achieve this by using their own mapping system. Thus, some (but not all) platooning systems will not work without cellular communication.

CACC vs. truck platooning

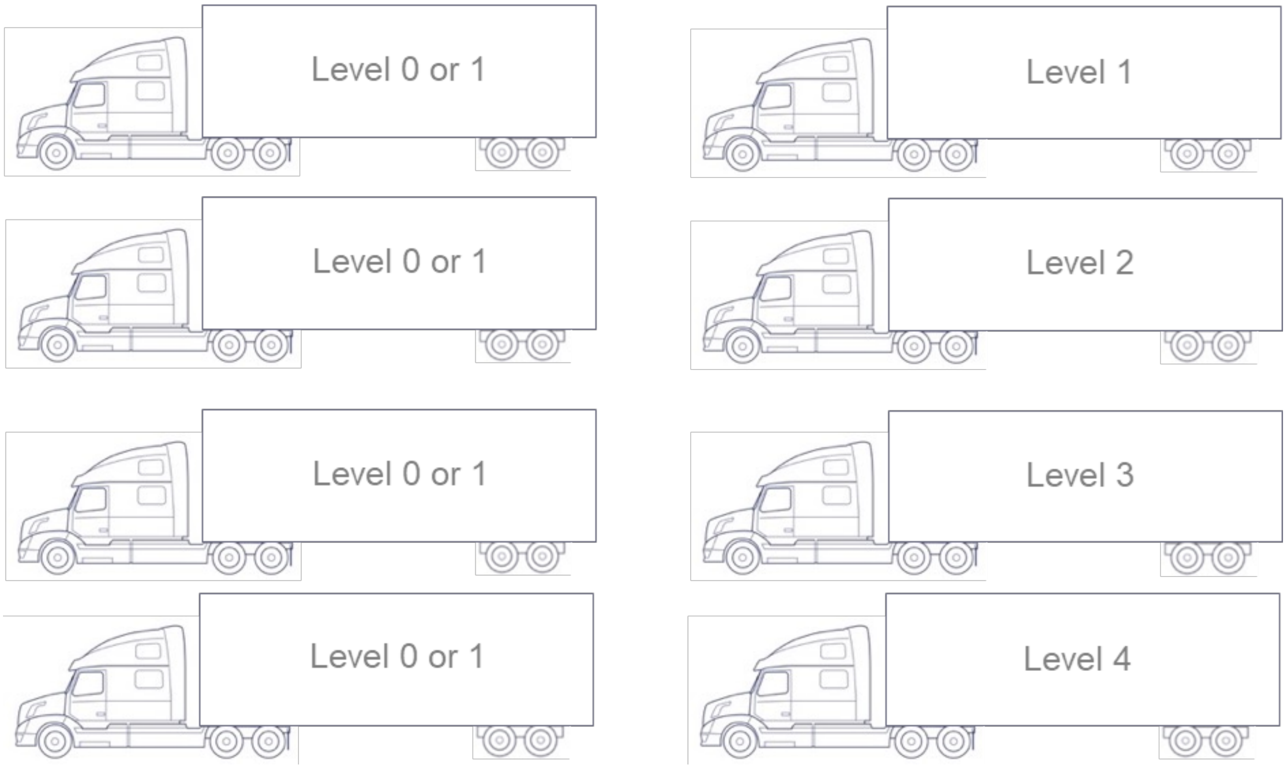
Heavy vehicle platooning may operate at different SAE levels. For instance, the following truck may only have automated longitudinal control (Level 1) or it may include lateral control as well (Level 2). Nowakowski et al. (2016) differentiates the terminology and refers to the Level 1 case as truck CACC, as it literally only needs CACC to operate. In the Level 2 case, the lateral control of the following truck may either be guided by the leading truck or by using LKA. Additionally, the leading truck may operate at different levels, ranging from Level 0 to (theoretically) Level 4. A range of truck platooning configurations is listed in Table 2.1 (Shladover 2010). In the same approach, Peloton, as one of the companies that develops a platooning system, has produced Figure 2.3 to illustrate the different configurations of truck platooning. In this report, the terminology Level *X* platooning is used, where *X* represents the SAE Level of the following trucks.

Table 2.1: Various truck platooning configurations

Lead truck automation functions	Following truck automation functions	Trailing trucks	Steering reference
Safety warnings	Automated + driver backup	1	Lead truck
Safety warnings	Automated + driver backup	1	LKA
Safety warnings	Automated + driver backup	2+	Lead truck
Safety warnings	Automated + driver backup	2+	LKA
Automated + driver backup	Automated + driver backup	1	LKA
Automated + driver backup	Automated + driver backup	2+	LKA
Safety warnings	Unmanned	1	LKA
Safety warnings	Unmanned	2+	LKA
Automated + driver backup	Unmanned	1	LKA
Automated + driver backup	Unmanned	2+	LKA
Unmanned	Unmanned	2+	LKA

Source: Shladover (2010).

Figure 2.3: Various truck platooning configurations



Source: Peloton (2018).

The algorithm employed by the following vehicle(s) may be different as well. Nowakowski et al. (2016) pointed out that a Level 1 truck platooning system typically uses a constant-time-gap strategy while a Level 2 platooning system typically uses a constant-distance-gap strategy. Since constant-distance-gap strategy is more intolerant to sudden manoeuvres, the implementation requires a more formal procedure and hierarchical control compared to a constant-time-gap strategy (Nowakowski et al. 2016).

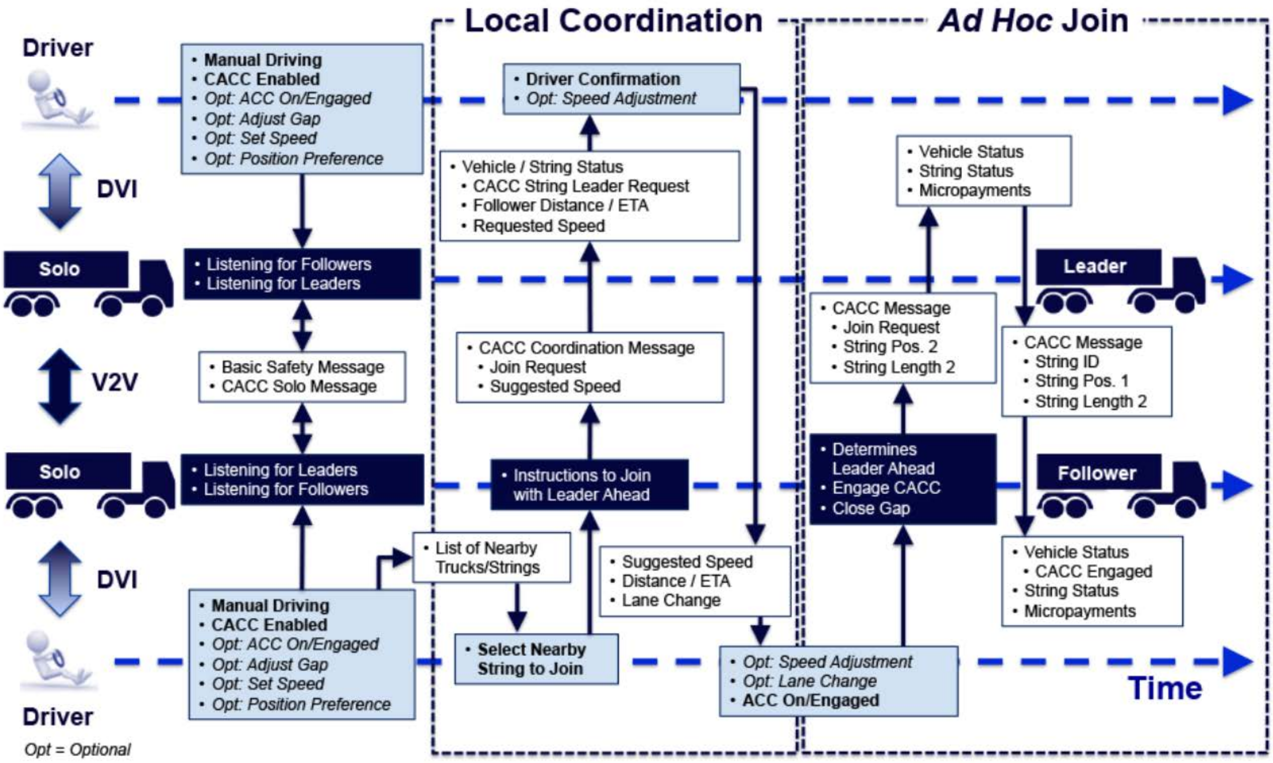
Truck platooning operations

The operational concept of truck platooning needs to consider: coordination strategies, joining manoeuvres, steady-state cruising, and splitting manoeuvres (Nowakowski et al. 2016).

The platooning may be coordinated locally, globally (centrally), or in an ad-hoc manner. Recall that the typical Level 1 truck platooning system uses a constant-time-gap strategy that does not require formal procedures, which makes it harder to manage centrally. The coordination typically uses a cellular network as time latency is not critical. Truck sequencing may also be considered, where the truck with the worst braking performance be put as a leader to ensure that the string can safely stop in the case of hard braking manoeuvres and the string can stay together on positive grades. Moreover, the length limit of the string, based on SAE standards, is limited to a 300 metre range of the 5.9 GHz DSRC system, which approximately corresponds to eight prime mover-trailer combinations, each 22.25 metres long, at a 0.6 second time-gap and a speed of 100 km/h. In remote areas, signal power could potentially be increased to reach more than eight. Furthermore, in remote areas, the effect on other road users may be minimal. However, in trials, the number of trucks in the platoon is usually limited to two or three to prevent lane-change obstruction to other road users and it is rare for logistics operations to require a larger number of trucks having the same origin and destination departing at about the same time.

The platoon formation/joining and splitting manoeuvres need to be managed carefully since they involve complex driving transitions from the driver to the ADS and vice versa. Nowakowski et al*.* (2016) provides detailed explanations of the break-downs of these manoeuvres when considering Level 1 truck platooning. As an example, Figure 2.4 shows the procedure of a platoon formation. This procedure consists mainly of three stages: initial communication, local coordination, and finally the joining manoeuvre. In the initial stage of communication, the drivers initiate the platooning system via the driver-vehicle interface (DVI), which then allows the system to initiate V2V communication. Then, the system will coordinate and provide instructions for the driver to follow, such as requested speed adjustment. Finally, the drivers perform manoeuvres as instructed by the system. Further details can be found in Nowakowski et al. (2016).

Figure 2.4: CACC formation activity diagram



Source: Nowakowski et al. (2016).

During steady-state Level 1 cruising, the drivers of the followers would still need to actively monitor the traffic and vehicle status. Additionally, the drivers may still need to manually adjust the set speed and gap settings, while the system advises the minimum set speed to maintain the platooning string. It is reported that a following distance ranging from 16.5 to 18 metres travelling between 80 and 120 km/h (equivalent to time gap between 0.5 and 0.8 seconds) is the limit at which the following driver feels comfortable (Nowakowski et al. 2016). It is also noted that, in contrast to passenger car platooning, visual occlusion poses concern to the following truck drivers when the gap is relatively small[6].

Safety equipment specification

The University of Florida Driver Assistive Truck Platooning (FL DATP) study (Crane, Bridge & Bishop 2018) reported that, based on outreach to the main platooning system suppliers in the USA (Freightliner and Peloton), platooning trucks have extensive safety equipment specifications, which are:

1. commercial air disc brakes on all tractor axles
2. radar-based forward collision avoidance and mitigation systems to automatically initiate braking when needed

[6] However, existing platooning systems use following distances of around 15 m and Peloton suggests that their test drivers are comfortable even at a 12 m gap.

3. commercial electronic stability control system
4. commercial Anti-Lock Braking systems on tractor and trailer
5. Platoon Operations Centre (POC) to monitor safety-relevant conditions and adjust platooning parameters as needed (note: it is not clear whether Freightliner plans to use something similar to a POC)
6. fail-operational measures so that platooning is gracefully dissolved if, for example, V2V communications is disrupted
7. driver engaged in the driving task (who can react early to cut-ins if needed)
8. truck-to-truck real-time video, plus driver-to-driver dedicated private radio comms, enabling drivers to maximize situational awareness via team work.

2.2.3 Driver State Monitoring (DSM)

A DSM system is a system that is able to detect and infer the state of the driver's awareness. There are two categories of DSM, one is concerned with driver's fatigue and the other is concerned with driver's attentiveness. A DSM system may also monitor both categories. An expert has suggested that DSM is required for SAE Level 2 and above.

In order to infer the driver's state of awareness, a DSM system may use the following measurements (Dong et al. 2011):

- biological measurements, such as electrocardiogram (ECG)
- physical measurements, such as per cent eye closure (PERCLOS), gaze direction, and head pose/tilt
- driving performance, such as standard deviation of lateral position
- a combination of the above measurements.

The DSM technology mainly relies on image processing and machine learning techniques. However, the underlying algorithms and measured parameters of DSM systems are not uniform. For instance, Rongben et al. (2004) proposed a system that only monitors mouth movement. This system may categorise a driver as: normal (mouth is mostly closed), distracted/talking on the phone (mouth opens and closes occasionally), or yawning (mouth is wide-open). However, it is noteworthy that even for a simple system such as this one, the DSM technology requires multiple, successive, complex steps, namely: face detection, lips detection, mouth location determination, mouth tracking, mouth feature extraction, and finally mouth movement classification.

More recently, it is more common to utilise a combination of several physical measurements Bergasa et al. 2006; Mbouna, Kong & Chun 2013). For instance, Bergasa et al. (2006) collectively measures PERCLOS, eye closure duration, blink frequency, nodding frequency, face position, and fixed gaze to determine the driver inattentiveness level (DIL).

Additionally, the algorithm may also measure the driving performance to further enhance the reliability of the DSM system (McCall & Trivedi 2004; Rauch et al. 2009). The driving performance may include standard deviation of lateral position, number of lane crossings, and the Steering Wheel Reversals (events where the direction of the steering wheel movement is reversed by a small finite angle).

Currently, some commercial passenger cars have introduced this technology (Dong et al. 2011). Saab's Driver Attention Warning System (DAWS) uses two miniature infrared cameras that measure eye blinking and driver's gaze to detect drowsiness and distraction (if the driver does not gaze to the 'primary attention zone' within a certain time limit). Toyota's Driver Monitoring System (DMS) may briefly apply the brakes if obstacles are detected and the driver has not been paying attention to the road ahead. Drowsiness detection is later added in the Toyota Crown System.

On the other hand, Volvo and Mercedes-Benz opted to use driving performance measurements in their DSM systems. Volvo's driver alert control (DAC) monitors the car's progress on the road and decides whether the car has been driven controllably or uncontrollably. Furthermore, the attention assist system (AAS) in Mercedes-Benz first observes a driver's behaviour to build a profile, which is then used as a benchmark to see if there is currently a large deviation from this profile.

There are also several commercial companies that produce DSM equipment. Seeing Machines[7] is a company that provides DSM by using in-vehicle video cameras to measure fatigue level. Optalert[8] provides a similar service, yet it uses its own unique fatigue measurements, namely the Johns Drowsiness Scale. SmartCap[9] is another company that produces DSM gear, yet it measures the wearers' electroencephalogram (EEG) to determine their fatigue level. Most recently, in addition to fatigue, GM Super Cruise[10] also monitors the driver's gaze location.

In relation to DSM in AV operation, Cabrall et al. (2016) suggest that DSM will be a key aspect in verifying the driver's readiness to transition into manual mode. More importantly, it may be used as a safety system that can automatically trigger automated driving mode in the case of driver's inattentiveness, such as in the case of Toyota's DMS.

2.2.4 Deployment Path

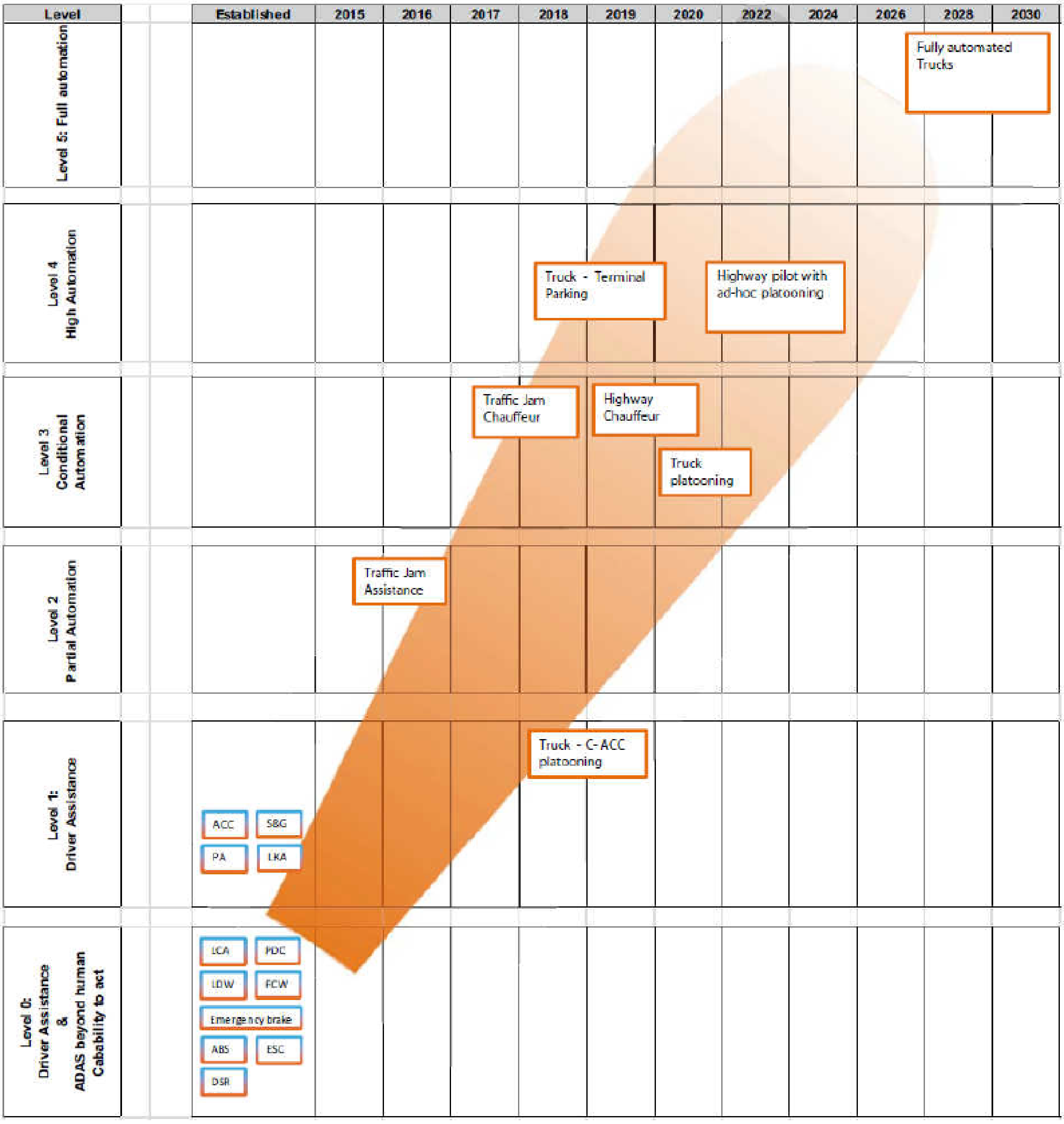
There are some reports that outline deployment paths for CAV technology (ERTRAC 2015; Alonso Raposo et al. 2017). For heavy vehicles, these reports agree that the next step the industry is heading is CACC development (Level 1 platooning) and traffic jam assistance at Level 2. However, these reports indicate that truck platooning deployment is at Level 3 instead of Level 1. This might correspond to the cases in Table 2.1 where the following truck is unmanned. Eventually, the fully automated (Level 5) truck is envisioned to be fully operational in 2030. The deployment path by ERTRAC is shown in Figure 2.5.

2.3 Infrastructure Requirements

Automated vehicles utilise various means to obtain information that allows them to perform the driving tasks properly. Initially, ADS mainly rely on sensors to detect the surroundings. These sensors are mainly used to detect road markings, traffic signs, and traffic lights. In addition, recent advancement of communication technologies has also influenced AV development (V2X), which can provide low latency communication systems, such as Dedicated Short-Range Communications (DSRC) and 5G (note that a vehicle can have both). These communication systems can be used by the vehicles to obtain various information[11], such as traffic light states, the position and speed of other road users (both other vehicles and vulnerable road users), real-time traffic information, and live HD digital maps including road/lane closures. Although not all the aforementioned features are relevant for regional areas, road operators may assist in introduction of AV by ensuring adequate provision of infrastructure to allow a safe operation of AVs on the roads[12].

[7] https://www.seeingmachines.com/
[8] http://www.optalert.com/
[9] http://www.smartcaptech.com/
[10] https://www.cadillac.com/world-of-cadillac/innovation/super-cruise?ppc=GOOGLE_700000001297222_71700000025000383_58700003076487421_p26082674580&ds_rl=1253750&gclid=CjwKCAjwmufZBRBJEiwAPJ3Lpvt6NL9WIazV5N_cyglZ4KocdF6J5iXmtWjRgQ4VqCVAFyV3tCHLMxoCDYQQAvD_BwE&gclsrc=aw.ds
[11] It has been pointed out by an industry expert that commercial development is not heading towards the use of communication systems.
[12] However, it has been suggested that commercial technology developers do not expect the road operators to do anything to accommodate their products.

Figure 2.5: AHV deployment path by ERTRAC. Note that the higher-level capabilities are likely more complex than just putting together the lower level technologies



Source: Alonso Raposo et al. (2017).

Several key road manager considerations to support AV have been identified in the literature (Nitsche, Mocanu & Reinthaler 2014; Austroads 2017). Generally, these can be classified into physical and digital requirements. Additionally, AV operations may also impact infrastructure design and operation.

2.3.1 Implications of AHVs on Physical Infrastructure

Austroads (2017) found that automotive manufacturers were developing automation technology with the goal of being able to safely operate on existing roads without the need to change existing road infrastructure. It was reported that the full benefits of Level 3+ CAV deployment cannot be harnessed until CAV technology matures to be able to correctly read the road environment in a highly reliable, predictable and safe manner.

In the short to medium term, physical infrastructure required to operate in concert to support CAV operation can be considered in three broad categories:

1. Infrastructure which affects a single AHV's ability to position itself safely on the road or 'read' the road environment. Examples include lane widths, vertical and horizontal curves (which affect forward visibility), intersection design, line marking, and signals and signage.
2. Structural systems which support vehicle safety, generally, and may require some special consideration for unique AHV characteristics (particularly heavy vehicle platooning). Examples include pavement design, barrier design and bridge and culvert design. This is collectively described as pavements and structures.
3. Other road design elements or facilities required to support AHV operation. This includes consideration for elements such as handling vehicle cut-ins from/to on-ramps/off-ramps (for vehicle platooning operation), prevalence of emergency or pull-off bays, connector roads, merging lengths etc.

ARRB is aware of the following areas of physical infrastructure design and maintenance that are likely to be impacted and require consideration by road managers, based on the findings of Austroads (2017):

- Road pavement and structure[13]:
  - Loads on existing bridges and pavements may be greater than original design assumptions requiring restrictions or modifications.
  - Design of new bridges and pavements may need to have different loading assumptions.
  - Design of pavements may need to be considered differently with AHV operation potentially resulting in increased rutting and surface wear if AHVs follow the exact wheel path of other vehicles in a platoon[14].
- Physical attributes:
  - Vertical and horizontal curves of roads may need to be considered differently if the road is expected to have AHV operation in the future, as on-board sensors may not correctly detect steep grade as objects (in earlier prototypes, at least).
  - Barrier design should consider impact loads from platooning vehicles, based on a risk assessment for the road.
  - Intersections – there is potential for coordination between vehicles and therefore intersections could be made more compact in the future.
- Static and electronic road signs:
  - Static signs – the standards for static signs (speed zone, advisory speed, give way, etc.) need to be consistently adopted; variations should be avoided.
  - Electronic signs – consideration needs to be given to the specifications of these signs to ensure that all road users (including AHVs) can read these signs.
  - Care in locating and orienting signs is just as important as the information on the signs.
- Line marking:
  - Consistency is vital and noted to be problematic for some vehicle manufacturers at present.
- Road certification/risk rating:
  - Evaluation and definition of roads highly likely to be required to define roadways that are suitable for specific vehicles and use cases (which may need to be done in collaboration with OEMs).
  - Requirements will include clear road markings, appropriate and consistent signage on the network and communication to users regarding which vehicles can operate on that roadway. Special use highways may be required to accommodate certain types of CAV traffic such as platoons of heavy vehicles.

[13] Several experts from academic, industry, and jurisdictions suggest that loading problems due to platooning may not be different than a road train's loading, which indicates further investigation is needed.
[14] This could be addressed by introducing a slight lateral offset onto the path of the following trucks.

  - An alternative approach to certification is to provide some guidance or framework, outlining where certain CAV use cases should or should not operate e.g. by using network operating plans (NOP).
- Maintenance:
  - Need for regular and consistent maintenance (including trigger points) is particularly important to CAVs given their reliance on delineation and signs.
  - New vehicle use cases, particularly heavy vehicle platooning may require a different consideration of maintenance regimes for structures and pavements, based on the outcomes of engineering analyses.
- Roadworks:
  - There is a need for consistency in the treatment of these environments. There are currently significantly different approaches between projects and across different jurisdictions.
  - It may be necessary to schedule roadworks and platoon operations for different times so that platoons do not need to manage the complexity of roadworks.

2.3.2 Implications of AHVs on Digital Infrastructure

AHVs will rely on a range of systems to operate effectively and safely as reported by Austroads (2017). This includes not only a range of on board systems and sensors, but also the use of data from other sources external to the vehicle. The following key forms of digital infrastructure appear to be directly relevant to the effective and safe operation of AHVs, and these should be considered by road operators in their planning for AHVs:

- **Data management and access:** this refers to the data required by an AHV to effectively and safely operate. This includes not only data about the physical road environment (e.g. mapping data attributes), but also road traffic condition data, weather data, and other data required to support operation of the vehicle's systems such as software updates, security certificates, diagnostics, etc. Note that this might necessarily be the responsibility of road operators.
- **Positioning services:** this refers to wireless services that enable a vehicle's driving system to know its absolute position, which it may then use to match against a map representation of the road network, and/or to fuse with relative positioning data that it receives from its on-board sensors. Absolute positioning services are commonly satellite-based services but could also include terrestrial services.
- **Communications technologies:** this refers to the use of wireless communication technologies, such as cellular, DSRC, RLAN/Wi-Fi, radio broadcast, satellite, etc. This digital infrastructure may be necessary to facilitate the reception and exchange of a range of data required by AHVs.

Pertinent issues requiring attention include:

- **Road data management**: It is anticipated that many AHVs will rely on road map data to operate. These map data products will be provided by service providers (or by using AHVs as probe vehicles for data collection). However, there may be some road data attributes for which road agencies are the authoritative source.
- **Positioning services**: AHVs may be reliant upon availability of absolute positioning services. Compatibility of positioning systems with major global vehicle markets such as Europe, North America and Asia will be important to allow mass-produced vehicles to be used on Australian and New Zealand roads. There may be a role for road operators to provide or to facilitate positioning technology in certain locations or scenarios.
- **Communication services**: The availability of communication services, typically cellular, has the ability to enable or preclude AHV operation. Road operators traditionally do not have to play a role in this space; however, they may need to be more proactive should market forces not provide appropriate services (for example in rural areas) or they may be required to augment services within areas of restricted coverage e.g. in tunnels or valleys.
- **Data ownership:** It is important to understand what the role of government is in collecting data and how this will be shared. Some companies are proposing the use of open data protocols while others are continuing to promote highly siloed vertical integrations, intent on controlling data streams. Note that current vehicles are also already generating data to some extent.

- **Support for proprietary models:** A key concern for road agencies is whether support should be provided for proprietary digital infrastructure. For example, if OEMs are to use their own 'clouds', will there be something road agencies (or other stakeholders) need to do to support these modalities?
- Standards and guidelines for data are currently non-homogenous in the CAV context: Standardisation and consistency may benefit AHV operation.
- **Road agency regulatory framework in a digital environment:** Road agencies currently manage many regulatory issues such as speed limits, access permits, roadworks, heavy vehicle restrictions, over height restrictions etc. The transition to integrate and maintain this regulatory environment within real-time digital context will be challenging as it may require a significant overhaul of existing systems as well as new skills and changed organisational culture to provide the level of real-time information required. Real-time information in regard to roadwork would be highly valuable and may indeed be essential.
- **Privacy and the Surveillance Devices Act and Regulations:** Road agencies and other organisations involved in the information supply chain will need to be judicious regarding the collection and management of data. All data collection, storage, distribution and utilisation will need to be in accordance with relevant laws, as it happens currently.

2.3.3 Infrastructure Design, Provision, and Operation

How highly-automated vehicles will be catered for and what the road environment will ultimately look like need to be resolved (e.g. geometric features, lane widths and intersections, provision of roadside barriers, traffic control, surfacing materials, weather events. etc.). For urban operation, there is mixed opinion as to whether the road will be substantially different or not in terms of its look or the materials and techniques used, i.e. will dedicated infrastructure (e.g. lanes for automated vehicles only) be necessary and/or the best option or can existing infrastructure be modified or in some cases used without modification, to the same overall effect (Hillier, Wright & Damen 2015). The rural and remote cases under consideration here are likely to be more limited in their potential for road modification; the lengths of road and the remoteness of locations will dictate minimal alterations to any existing infrastructure.

Whether certain roads will become obsolete and hence, need to be decommissioned will also require consideration. Land requirements for new/future roads will almost certainly change and will need to be verified over time. It is already known that road agencies can provide infrastructure (e.g. line markings, signs) that can be 'read' successfully by vehicles, but a decision needs to be taken now on whether roads at the planning or partial construction phase at the current time need to be suited for the use by highly automated vehicles (and if so how to do it).

It has been suggested that the most logical approach is for road agencies to agree and communicate a number of stages or visions for a road, i.e. from current provision through the transition to a situation dominated by a self-driving fleet. By default, this will also require a minimum level of infrastructure provision to be determined under which highly automated vehicles can operate. Australia's vast (often remote) and typically ageing infrastructure will need to be given due consideration.

It is likely that current service-level requirements will no longer be appropriate and will require adjusting for highly automated vehicles. The network will still need to be able to reconfigure/adjust when required for roadworks and upgrades etc. This will ultimately mean finding effective ways of transmitting temporary or short-term locational data to highly automated vehicles close by (i.e. short-term messaging which may be achieved by signage).

2.3.4 Additional Infrastructure Considerations for AHV Platooning Use Case

Constraints on road type and operational challenges near on-/off-ramps

In the case of heavy vehicle platooning, there are some additional considerations relating to infrastructure. A platoon of trucks may prove to pose some challenges to other road users when they want to change lanes or overtake. On a dual-carriageway, the problem can be partially addressed by dissolving the platoon near on-ramps and off-ramps[15], as was discovered during the European Truck Platooning Challenge (Alkim et al. 2016) (which may be unique to Europe due to typically shorter ramps). However, on a single-carriageway, a greater risk and inconvenience would be faced with other road users since they must overtake multiple trucks either at once (if the platoon is not dispersed) or successively (if the platoon is dispersed). Either way, the necessity to consistently engage and disengage would imply that completely unmanned following trucks is infeasible. Having said that, there are not many other road users in remote and regional areas. Therefore, a potential solution includes limiting the platooning operational areas based either on road types or low traffic volume or time of day or night when other road users are far less likely to be encountered (such that decoupling may be avoided).

Additionally, a bridge loading issue is commonly flagged when discussing platooning operation. However, based on the results of the consultation (presented in Section 4), there has been no clear evidence on this issue and, in fact, some experts suggest that this might not be an issue at all. Thus, further investigation is needed.

Cellular connectivity

Another important point is that Peloton, an example of platooning systems, requires an operation centre to manage the logistics of the platoon operation. The in-vehicle units need to communicate with the operation centre to obtain authorisation to platoon. This is important to manage the safety of the platooning systems, for instance in relation to its ODD. As a result, this system requires periodic connectivity to the operation centre for coordination and authorisation of platooning. Thus, without a stable connectivity, the platooning operation will often be interrupted as it will not receive authorisation regularly. However, this operating model is unlikely to be encountered with platooning systems developed by truck OEMs.

2.4 Regulatory Requirements

The National Transport Commission (NTC), in collaboration with Austroads, has released several publications addressing regulatory requirements for AV operations in Australia, including establishing guidelines for AV trials in Australia (NTC 2017e), establishing safety assurance systems of AVs (Mitchell et al. 2017; NTC 2017f, 2018a, 2018c), developing legal reform options to clarify how current driver and driving laws may apply to commercially deployed automated vehicles (NTC 2017b, 2018b), and clarifying safety related definitions for policy making (NTC 2017c, 2017d). This work program is aimed to cover the whole-of-life cycle of AVs that are going to commercially operate in Australia and New Zealand.

A summary of the trial guidelines is provided in Table 2.2, whereas illustrates the end-to-end post-trial regulatory system.

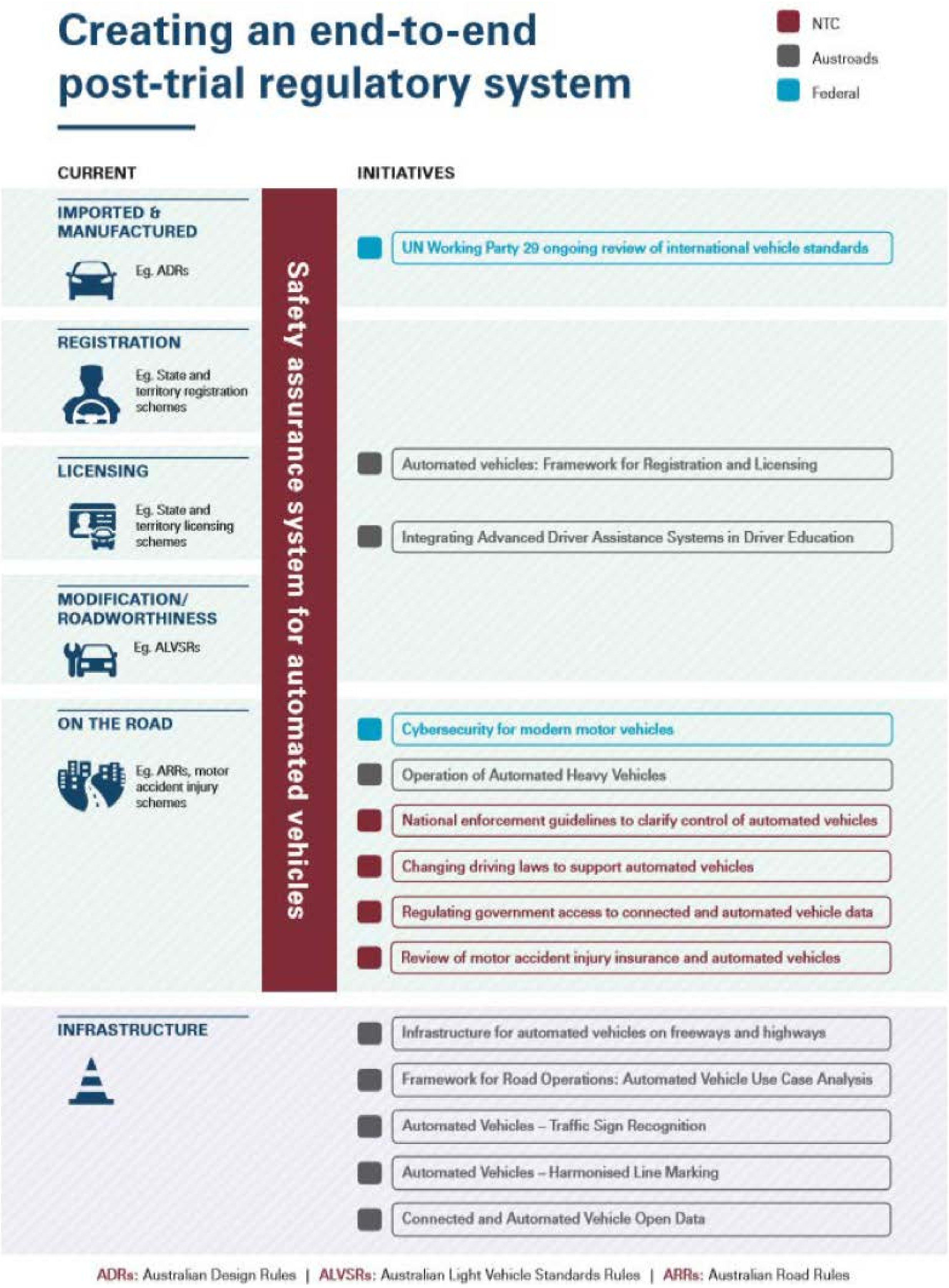
[15] The University of Florida Driver Assistance Truck Platooning (FL DATP) project suggests that this is not always necessary and can be decided during operation based on the driver's judgement.

Table 2.2: Guidelines of AV trials by NTC

Key management criteria	• Trial location • Description of the technology being trialled • Traffic management plan • Infrastructure or network requirement • Stakeholders and public engagement • Managing change
Insurance	Appropriate insurance could include: • compulsory third-party insurance • comprehensive vehicle insurance • public liability insurance • product liability insurance • self-insurance • work or occupational health and safety insurance
Safety management plan	• Security of the automated system • Risks to other road users • Risks to road infrastructure • System failure • Appropriate transition processes between automated and manual mode • Presence of human driver • Pre-trial testing • Driver training • Driver fitness-for-duty • Appropriate vehicle identifiers if necessary
Data and information	• Data for serious incidents, which may include: time, date, location, automation status, traffic conditions, road and weather conditions, vehicle information, sensor information, and identity of vehicle operator • Data for other incidents, including: near misses, when a human takes back control of the vehicle, a public complaint regarding the performance of the vehicle • End-of-trial report • Commercially sensitive information needs to be respected by road agencies
Implementation	• Cross-border trials need to be arranged with all relevant state road agencies • Existing trials will operate under the existing arrangements • Transition into deployment needs ongoing dialogue • The guidelines are not for large-scale commercial deployment • Trials that are commercial in nature may be permitted, but not for large-scale deployment • Vehicle limits for trials • Time limit for trials

Figure 2.6 shows the initiatives to create an end-to-end post trial regulatory system proposed in the NTC Regulation Impact Statement paper on safety assurance for automated driving system.

Figure 2.6: NTC proposed initiatives to create an end-to-end post trial regulatory system



Source: NTC (2018c).

Therefore, the principles to perform AV trials in Australia are already in place. However, the guidelines do not detail any safe deployment framework for each specific use case. Thus, although jurisdictions have the authority to provide trial exemptions (on a case-by-case basis), they do not have any specific guidelines on how these trials are to be safely conducted.

It is noteworthy that the guidelines provided by the NTC are only intended for trials and not for commercial deployments (NTC 2017e). An earlier report by International Transport Forum (2015) has also indicated that current regulations are generally developed only to accommodate trials. It also adds that the regulatory tasks are further being complicated by the nature of market-driven deployments of AVs. Therefore, this means that the challenge of regulating AV commercial deployment is relatively unaddressed and is one of the key operational boundaries of AHV operations in regional areas.

Road rules

The NTC has assessed existing road rules and identified the following problems (NTC 2017b):

- Current driving laws and offences assume a human driver.
- An ADS is not a person and cannot be legally responsible for its action.
- Current law does not provide for a legal entity (the Automated Driving System Entity, ADSE) to be held responsible for the actions of the ADS.
- Some legislative duties and obligations given to drivers could not be controlled by the ADSE if an ADS is the driver.
- Safety duties may need to be carried out by someone else if the driver is an ADS and legislation would need to clarify who has the safety duty.
- Control and proper control of a vehicle if an ADS is driving are not defined.
- Legal obligations to ensure readiness to drive.
- Compliance and enforcement.

Following this, it has been proposed that (NTC 2018b):

- The ADS is in control when it is engaged in Level 3 or above.
- The ADSE is responsible for complying with DDT obligations when the ADS is engaged.
- The ADSE is only responsible for tasks within its control.
- Readiness-to-drive obligations of the users of an AV are needed.

Safety assurance system

NTC (2017f, 2018a, 2018c) has also proposed a model for an AV safety assurance system, where the ADSEs are mandated to self-audit the safety of their AVs. The final preferred option is to introduce a safety assurance system with a dedicated national agency for AV safety (NTC 2018c). The self-assessment is based on the following performance-based safety criteria:

- Safe System design and validation processes
- ODD
- HMI
- compliance with relevant road traffic laws
- interaction with enforcement and emergency services
- minimal risk condition
- on-road behavioural competency
- installation of system upgrades

- testing for the Australian road conditions
- cybersecurity
- education and training.

Driver state monitoring

Driver inattentiveness in the following trucks of a Level 2 (or above) platoon may become a concern as the driver is not fully engaged. DSM may assist in alleviating the safety concerns during driving mode transition of AHV deployment. In fact, it is part of the recommendation of the report following Tesla's fatal crash, which was caused by driver's inattentiveness (National Transportation Safety Board 2017). This implies that DSM might be compulsory for the operations of AHVs, or AVs in general, at Level 2 and above.

Liability

Furthermore, Wagner, Moran and Lukuc (2017) identified potential concerns in liability of truck platooning incidents through literature review and interviews. Their review pointed out that although the liability most likely will shift from the driver to the technology manufacturer, some interviewees were of the opinion that shift might not occur, or it might not be as straightforward since the lead truck might still be manually driven. Additionally, the adoption of the technology might be accelerated by market competition (caused by early adopters) such that the regulation might not be ready yet. Liability cannot be generalised because it tends to be very incident-specific. Depending on the specific circumstances of a crash, multiple parties could be at fault in different ways. Requiring comprehensive event data recorders on the vehicles and ensuring access to the recorded data by all relevant parties (public and private) is one way of maximizing the likelihood that the liability will be assigned rationally and equitably for any specific crash.

Regulation related to platooning

The following are several regulations that are related to platooning:

- **Following distance rules.** The regulations relating to platooning operation, specifically for heavy vehicles, may be quantitative or qualitative. For instance, Australian Road Rules mentions that a vehicle has to follow another vehicle within a safe distance without specifying any specific requirements. However, it was also specified that a road train and a long vehicle (other than a road train) need to drive behind a long vehicle with a following distance of 200 metres and 60 metres, respectively. The following distance rule does not apply when travelling on a multi-lane road, in a built-up urban area or when overtaking, but will be applicable for most remote and regional roads. The New Zealand road rules also consider the road type but differ in that they refer to a driver and a minimum following distance related to the vehicle's stopping distance. In addition, a minimum distance is provided for any road type, which is related to the travelling speed. For example, if the driver's speed is 90 km/h or greater, the minimum following distance is 36 m. There are other rules that may potentially impact truck platooning operations including stacking distance[16] and acceleration.
- **ITS class licence.** Australian Communications and Media Authority has issued the *Radiocommunications (Intelligent Transport Systems) Class Licence 2017* that allows the use of complying wireless communication devices to operate at 5.9 GHz frequency bandwidth for ITS purposes. The licence impacts the application of low-latency V2V equipment (DSRC) that is essential in platooning operation.
- **Platooning access/authorisation.** Additionally, recall that AHV platooning (depending on the gap, number of trucks, and AV level) may pose a great disruption to the surrounding traffic flow because a platoon may block a significant part of a lane that prevents lane changing or cut-in. Therefore, it might be necessary to impose restrictions on the road types or part of the networks on which truck platooning may occur (which presumably is a subset of the ODD of the single automated vehicle).

[16] The stacking distance is the length of road required to store vehicles stopped in a queue at an intersection.

2.5 Key Success Metrics

Any operational trial must have established metrics for determining its success. This will include success from the perspective of road managers, the operators, and more inexplicitly, the community. The literature review was focussed on the road managers' perspective. The benefits for transport operators are not within the scope of this review but can be expected to be considerable based on the interest and current investment of transport operators to explore the potential of automated technology. Transport operators' benefits will be explored during industry consultation.

Table 2.3 lists the commonly identified benefits of AV operations from the perspective of the stakeholders.

Table 2.3: Benefits matrix

Benefits	Stakeholders receiving benefit/impacts		
	Road owner	Transport operator	Community
Safety	●●	●●	●●
Road operations	●●	●	–
Fuel saving/sustainability	●	●●	●
Economic productivity	●	●●	●
Social	●	–	●●

Note: ● Indicates an indirect benefit. ●● Indicates a direct benefit.

Section 2.5.1 will discuss these benefits from a road manager's perspective by detailing the impact of AV operations on these five aspects.

2.5.1 Measuring the Benefits of Automation

In general, vehicle automation has the potential to increase safety and efficiency. In terms of safety, the ability of AVs to react faster to sudden braking is far superior compared to human drivers if the vehicles are connected. Consequently, an increase in transport efficiency can be achieved, such as through smaller headways to increase the road capacity. In fact, due to the advanced V2V (or V2X in general) technology that is becoming more ubiquitous, these benefits should be more pronounced since the future AVs should be able to anticipate events rather than being reactive. A prevalent example is heavy vehicle platooning (or platooning in general). Without the use of communication systems with sufficiently low latency, a vehicle platoon is bound to amplify a small disturbance in the vehicle speed causing unstable driving behaviour, referred to as the 'string instability' (Liu et al. 2001; Seiler, Pant & Hedrick 2004; Middleton & Braslavsky 2010). The prevention of the string instability is achieved by coordinating the acceleration and deceleration of the trucks within the platoon, rather than relying on the reactive capability of the ADS. Therefore, it is of interest to identify how all these benefits translate to the operations of AHVs in regional areas.

Safety. One of the important motivations of AV operations is safety. Driver error has been suspected as the main reason behind over 90% of all crashes (National Highway Traffic Safety Administration (NHTSA) 2008) and contributes to 10–30% of road deaths (European Transport Safety Council 2016). By removing driver-related errors from the equation, AV is believed to be able to reduce the number of crashes dramatically (KPMG 2012), as even the lowest 'automation' in the form of electronic stability control (ESC) has reduced the number of crashes by up to 20% (European Transport Safety Council 2016). Additionally, some trials have found that a higher compliance of speed limit is achieved through automation (Alkim et al. 2016). Furthermore, driving heavy vehicles in a certain domain, such as on steep descents[17], is particularly challenging such that special safety features are recommended to manage the risk (Austroads 2015). Finally, a heavy vehicle is required to be equipped with the latest safety technology, such as AEB that reduces approximately 80% of rear-end crashes (Crane, Bridge & Bishop 2018), before it is allowed to use a platooning system.

[17] Note that this might not be a concern in regional areas of WA. Also, automation technology providers generally do not allow automated mode on steep grades.

Road operations. The advent of automation will change how the roads are being operated. Firstly, it has been pointed out that platooning has the potential to improve the road capacity[18] by reducing the following distance between vehicles. Although platooning might not be applicable to an urban environment, the headways of non-platoon can still be reduced compared to human drivers. Note that current ACC technology may already be able to achieve this, yet regulation barriers exist that limit the gap between vehicles to a minimum, such as Australian Road Rules limitation on following a long vehicle. Secondly, it has been proposed that AVs would reduce crash severity which would imply fewer safety features are required (Somers & Weeratunga 2015). Note that this is not necessarily true as a few of the previously mentioned literature identified the need of special considerations for protection of vulnerable road users in the case of system failures (Nitsche, Mocanu & Reinthaler 2014).

Fuel saving. One of the key benefits of automation, particularly for heavy vehicles, is fuel savings. It can be achieved, for example, through optimised driving trajectories performed by the ADAS (Li et al 2015). Furthermore, close-following platooning, as one of the first key automation deployments for heavy vehicles, enhances the fuel savings further by reducing the drag experienced by the trucks within the platoon. It has been found that, in a two-truck platoon with 10–30 metre following distance, the fuel savings experienced by the following truck and the leading truck are up to 12% and 5% respectively, resulting in the 'team' fuel savings ranging from 5% to 8% on average (Tsugawa 2013; Lammert et al. 2014; Humphreys et al. 2016; Bishop et al. 2017; Turri, Besselink & Johansson 2017). In order to illustrate the significance of these savings, the following data is used to estimate the reduction of cost and CO_2 emissions due to truck platooning of road trains:

- Road train freight volume in 2015–2016: 29 356 million tonne-km (Australian Bureau of Statistics 2016)
- Road train payload range: 50–70 tonnes[19] (Australian Bureau of Statistics 2016)
- Road train fuel use: 70–80 L/100 km (Australian Bureau of Statistics 2016)
- Diesel fuel retail price: 110.5c/L Adelaide wholesale price as of 22 Aug 2017 (Australian Institute of Petroleum 2017)
- Diesel fuel CO_2 emission per litre: 2.67 kg (BP 2006; Driving Tests 2018; University of Exeter n.d.; Ecoscore 2018).

Table 2.4 shows the potential impact of the fuel saving capability of platooning assuming 100% uptake for road train volume.

Table 2.4: An estimation of the benefits of fuel saving of truck platooning for interstate road freight in Australia

Freight volume (million tonne-km)	29 356
VKT (million km) based on 60 tonnes average payload	489.27
Total fuel use (million L) based on 75L/100 km average fuel use	366.95
Maximum (100% uptake) fuel savings potential at 5% efficiency (million L)	**18.35**
Fuel cost savings	**$20.27 M**
CO_2 reduction (tonne)	**48 987.83**

To put the figures in Table 2.4 into perspective, the maximum potential cost savings and the CO_2 reduction are approximately 20% of the benefits provided by the Performance Based Standard (PBS) Scheme (NTC 2017a), which are 94 million litres and 250 000 tonnes respectively. Note that the figures in the above table only consider road trains, which really highlights the potential impact of nation-wide deployment of automation technology to improve the sustainability of Australian freight in general. Therefore, considering the significant impact of platooning on heavy vehicle operations, fuel saving should be a key part of the success criteria of any AHV platooning trials.

[18] Again, this might not be of great concern in regional areas of WA.
[19] Road train payload was based on operating at general mass limits.

Economic productivity. Due to the cost savings and efficiency that heavy vehicle automation brings to the industry, it will assist in boosting the economic productivity of the freight industry in Australia. Firstly, as previously mentioned, driver shortage is a serious threat that needs to be addressed (Carey 2016). Bringing automation is expected to increase the attractiveness of the job due to reduced workload. Secondly, Bellamy and Pravica (2011) suggest that a successful AHV operation would establish Australia as a centre of excellence in the mining sector, akin to Silicon Valley in the technology sector. This would keep the interest of big mining companies to maintain their operations in Australia. Finally, discussion with industry has also identified the potential reduction of economic costs borne from unsafe drivers due to loss of productivity.

Social. Several social benefits of trucks automation in the mining industry have been identified from the literature. Firstly, it would increase the technical requirement of the workforce (Bainbridge 1983; Bellamy & Pravica 2011). Indeed, operating an automated truck, particularly the earlier prototypes, as demonstrated during the European Truck Platooning Challenge (ETPC), can be quite a difficult task and is best performed by experienced drivers (Alkim et al. 2016). Therefore, this is an opportunity to increase the skill level of the Australian workforce. Secondly, Bellamy and Pravica (2011) claim that a smaller workforce at each mine site would provide a mentally healthier work environment, where the sense of being 'lost in the crowd' can be prevented resulting in a better sense of identity among the workers (which may or may not be applicable in the Australian and New Zealand context).

In summary, heavy vehicle automation may provide a wide range of benefits that, arguably, justify the need for Australia to perform trials to gain better insights on how all these benefits translate to Australian conditions in regional areas. Table 2.5 summarises these benefits and provides an idea of their relevance to regional areas in Australia.

Table 2.5: Summary of benefits of AHV operations and their relevance from a road manager's perspective

Category	Benefits	Potential impact	Relevance
Safety	Reducing driver-related errors	High	High
	Speed limit compliance	Medium	High
Road operations	Increasing road capacity through reduced headway	High	Low
	Fewer safety features	Undetermined	Medium
Fuel savings	Reduction of fuel use and CO_2 production	High	Medium
Economic productivity	Attractiveness of truck driver jobs	High	High
	More jobs due to operations of previously unprofitable mines	Medium	High
	WA as CoE in mining industry	Medium	High
Social	Increased skill of taskforce	Medium	Medium
	Better mental environment for workers	Medium	High

2.6 Impact and Risk Management

Despite all the benefits offered by AHV operations, there are some concerns that need to be addressed. At this stage, it is still not completely clear how other drivers would interact and behave around AVs. Furthermore, there might be some impacts of AV operations to infrastructure. In this regard, case studies would prove useful in providing a starting point for discussion. Among the many AHV trials (mostly platooning projects), the review focusses on two documents that address AHV operations on the roads. The first covers the risk management of AHV trials, and the second addresses several operational considerations (similar to ConOps) of AHV trials.

Table 2.6, mostly drawn from the 'ETPC Lessons Learnt' report (Alkim et al. 2016), summarises the risk and impact of AHV operations to road operations, particularly related to platooning (earlier prototype).

Table 2.6: A list of identified risks and impacts of automated heavy vehicle operations and the corresponding mitigation strategies

Identified impact/risk	Mitigation strategy
Disturbance of traffic flow due to close following distance (harder to overtake)	• Recognisability of AHVs, especially those in platoons • Prescribed following distance • Larger following distance at on- and off-ramps (or even manual mode only) • Restrictions on maximum speed and specific manoeuvres • Public education on how these AHVs behave • Restrictions of operations only on two-lane roads
Increased road wear and tear, such as in the form of ruts	• Restrictions on maximum load and division of load • Restrictions on bridges
Limited ADS capability in complex traffic situations	• Restrictions in complex situations such as motorway junctions, high density traffic, specific weather conditions, intersections, on- and off-ramps
Driver unfamiliar with transition of control, particularly during unexpected fall-back events (such as when a platoon is broken up by an 'invading' vehicle)	• Technical/training requirements of the truck drivers • User interface design requirements
System failure at specific infrastructure, such as tunnels, slopes and curves	• Restrictions on the corresponding infrastructure
[Platooning only] Lane changing performed individually	• Proper driver training to coordinate team work • Manual mode during lane change
Driver trust/acceptance of ADS	• Proper training • Appropriate human machine interface (Hanelt, Hildebrandt & Leonhardt 2016)

Additionally, a report detailing the results of a feasibility study of truck platooning on UK roads offers a list of important considerations (with some of them overlapping with the findings of the ETPC) for performing trials (Ricardo, TRL & TTR 2017), which is reproduced in Table 2.7 below.

Table 2.7: Several considerations for performing truck platooning trials as identified during the UK truck platooning feasibility study

• ADS system parameters should be appropriate for safe operations. • The number of vehicles in the platoon (with a maximum number specified). • The location and timing of the trials. • Handling mismatch in driving performance (such as by using the same vehicle type). • Avoid hazardous loads. • Avoid complex environments, such as those with lane width restrictions. • Avoid extreme weather conditions (such as ice and snow), yet it is important to include common occurrences (such as night time).	• Obtain operational approval and/or exemption permits for trials. • Proper training for drivers performing the trials. • Proper phasing of trials: - ADS adaptation for local operations, such as conversion to right-hand driving. - Pilot testing on test tracks (and train drivers). - Testing on private roads or roads with low volume of traffic. - Testing on the 'easier' parts of the normal haulage operations. - Testing on more complex parts of the normal haulage operations.

Source: Ricardo, TRL & TTR (2017).

Furthermore, Department of Mines and Petroleum (2015) of WA published a code of practice that outlines a safety plan for operations of AHVs in mines. This code of practice is summarised in Table 2.8.

Table 2.8: Safe mobile autonomous mining code of practice

Management aspect	Considerations
Safety and risk management process	• Communication and consultation for risk management • Information for risk management is well managed • Risk identification • Risk analysis • Risk evaluation and management • Monitoring and review • Documentation
Information, instruction, training and supervision	• Information available for task completion • Personnel are well instructed • Personnel are well trained • Adequate supervision
Introduction to general hazard controls	• Suitability and design of operational environments • Identification of AV technology limitations • Identification of operational process limitations • Competency of personnel • Records and change management
Mine planning and design for hazard control	• Designing and planning for autonomy use cases • Managing interactions with AVs • Infrastructure support • Suitable operating environment • Change management
System planning and design for hazard control and functional safety	• Roles and responsibilities of systems operators and builders • Appropriate system design • Fail-to-safe state • Review and audit process • Change logs • Systems security
Commissioning hazard control	• Roles and responsibilities of systems operators and builders • Risk management process • Formal approval process • Commissioning planning and test plan • User acceptance testing
Operational hazard control	• Management and supervision • Technical knowledge within operation team • Roles and accountabilities • Competency validation • Change management • Rules for interaction with AVs • Human factors • Performance monitoring • Area security and control • Tools, processes, and technical support
Maintenance hazard control	• Scheduled maintenance and inspection • In situ inspection and servicing • Base platform for AVs and systems • Recovery procedures • Area and activity isolation • Condition monitoring and diagnostics • Calibration and testing
Emergency management	• Isolate all, or part of the autonomous area • Shut down the AVs

The lists in Table 2.6 – Table 2.8 can be used as a baseline to develop more comprehensive safety plans and concepts of AHV operations in regional areas. Depending on further consultation, the resulting safety plans and concept of operations may expand, modify, prioritise, or narrow down the lists. The results of the consultation are presented in Section 3.1.

2.7 Summary of Findings

Having reviewed the literature, it is important to understand what this means in the local context in Australia. The summary of the findings is as follows:

- Two use cases for AHVs in remote and regional areas are auto-pilot and truck platooning.
- Road infrastructure in remote and regional areas might pose a challenge for AHV operation due to single-carriageway and potentially inadequate lane markings.
- The lack of cellular connectivity in remote and regional areas might prevent some commercial platooning systems, such as Peloton, to operate.
- Regulatory requirements in Australia are ready for trials, but not for commercial deployments.
- There are some benefits that are associated with AHV operations, but not all of them are relevant for regional areas in Australia. Additionally, some of these benefits are not directly measurable during trials.
- Other trials have provided a good starting point for developing safety plans and concepts of operations for AHV deployment in regional areas of Australia.

Firstly, remote and regional areas in Australia lack the physical (and to some extent digital) infrastructure required to operate truck platooning, which is one of the key use cases of AHV operation. However, infrastructure requirements might have stop-gap solutions (such as by providing appropriate concept of operations).

Secondly, as previously pointed out, the regulations are in place for trials of AVs in Australia, but they are yet to extend to include commercial deployments. The effort to establish end-to-end post-trial regulations for AV deployments is still ongoing.

Thirdly, it is noteworthy that some of the identified benefits (that are relevant to road operators) of heavy vehicle automation may not be able to be immediately measured during a trial, such as social and safety (as data evidence of safety benefits need to be collected over a long period of time to gather enough samples). One of the most commonly used metrics of AHV trials is fuel savings (Tsugawa 2013; Lammert et al. 2014; Humphreys et al. 2016; Bishop et al. 2017; Turri, Besselink & Johansson 2017). In fact, a standard has been published by SAE to ensure appropriate comparison of fuel consumption (SAE International 2012). Secondly, an operational model of a business can be used to calculate an estimate of the economic productivity. Finally, another metric used to measure the success of a trial is whether the trial can be safely completed.

Finally, much can be learned from other trials around the world in terms of managing the risk and impact of AHV operations, some of which have been summarised in Table 2.6 – Table 2.8. These lists can be used as a baseline to develop a more tailored safety plan and concept of operation that is relevant for operations of AHVs in regional areas of Australia.

Having reviewed the relevant literature and extracting the important information, the next two sections present the consultation results with experts, local industry and stakeholders to tailor these findings to fit the local context. Additionally, the consultation has further enriched the findings of this research project by identifying several important operational aspects of running AHV trials that have not been covered by this literature review.

3. Impacts and Opportunities

3.1 AHV Use Cases in Remote and Regional Areas

The literature review included a discussion on AHV opportunities in remote and regional areas. Although there are a few AHV opportunities in general, only two are considered relevant in remote and regional roads:

- platooning at various levels
- standalone automated highway driving at various levels.

Additionally, the review also identified DSM as a complementary technology to enable safer automation of heavy vehicles at certain levels of automation. This section will build upon these findings to create several more detailed use cases.

The creation of these use cases can be broken down into selecting several key parameters, as shown in Table 3.1 below. Note that, in this report, we are excluding Level 4 and 5 because this technology will not be mature enough for deployment within the next 5 years.

Table 3.1: Use case parameters

Category	Parameter	Parameter value
DDT	Automation technology	• Level 1 truck platooning (CACC) • Level 2 truck platooning • Level 1 standalone automation • Level 2 standalone automation • Level 3 standalone automation relying on HD maps
Vehicle	Trailer combination	• Semi-trailer • B-double • Road train
ODD	Road type	• Single-lane single carriageway • Multi-lane single carriageway • Single-lane dual-carriageway • Multi-lane dual carriageway
ODD operation	Road surface	• Unsealed road • Sealed road with no kerbside lane marking • Sealed road with kerbside lane marking
	Environmental condition	• Day/night-time • Dry road only • Temperature range
	Traffic condition	• Medium volume of other traffic • Low volume of other traffic • No other traffic
	Speed range	• Walking (0–10 km/h) • Traffic jam (0–20 km/h) • Urban (0–40 km/h) • Medium/arterial (40–80 km/h) • Motorway (> 80 km/h) • Any other speed range
	Other considerations	• DSM required • Automated vehicle identification (for other road users) • Automation parameter (such as platooning following gap)

Several sample use cases derived from these parameters are discussed below. More importantly, each use case will have its own associated benefits. Thus, this can be used as a guideline in selecting the appropriate use case that aligns with the objectives of the industry.

3.1.1 Driver Assistive Truck Platooning on Dry, Sealed Roads, with No Other Traffic

This is one of the most straightforward use cases where there are already a number of experiments performed, both on test tracks and on roads (both closed and open). Therefore, the technology is already available. Since these platooning systems are mostly developed for left-hand drive, some adaptations may be required to bring in these technologies to Australia.

This use case has several variants. However, the scope of this use case is limited to:

- sealed roads, where these platooning technologies have been tested
- no other traffic, which is deemed to be a common occurrence in remote and regional areas
- dry weather condition for safety
- vehicle identification is required to inform other road users that may be encountered.

Thus, the variants of this use case are:

- Either Level 1 or Level 2 truck platooning technologies.
- Since there is no other traffic, it can operate on all road types.
- Sealed roads are required, yet no requirements on lane marking since the drivers (or the lead driver) are still in control of lateral movement.
- Temperature may vary, yet no extreme temperatures are allowed due to the possibility of compromised braking performance.
- DSM is required for Level 2 (since the following drivers are not in control).

3.1.2 Level 3 Automated Highway Driving on Dry, Sealed Roads without Kerbside Lane Marking, with No Other Traffic

This use case assumes that there is no other traffic associated, such as in private roads on mine sites. The truck utilises high precision positioning, such as SBAS or HD map with real-time kinematic to navigate the roads.

3.2 Stakeholder Use Cases

Several commercial industry stakeholders were consulted to build detailed use cases that are specific to remote and regional areas. The three stakeholders that were approached are representative of typical fleet operators in remote and regional areas. The consultation outcome is several sets of parameter values that each will form part of a use case description. This is outlined in Table 3.2.

Table 3.2: Questions for stakeholders to build up use cases

Parameter	Stakeholder A	Stakeholder B
Location	Between Leinster and Kalgoorlie	Between Perth and Northam
Route	100 km motorway	100 km motorway
Road type	Single-lane single carriageway	Multi-lane double carriageway, and single-lane single carriageway
Road surface	Sealed road	Sealed road
Environmental condition	All conditions (24/7 operation)	
Traffic condition	Regional: low	High to medium
Trailer combination	Triple and quad, multi brand, < 7.5-year-old	Mostly triple, some single
Prime mover	Multiple brand, < 5-year-old	Multi brand
Fleet	750	580
Motivation/goals	Financial ROI, safety	Fuel savings
Opportunities of interest	Platooning and single vehicle automation	Platooning
Automation parameter requirement	N/A	N/A
Use case	Level 3 single AHV[20] on sealed roads, all elemental conditions, with low traffic conditions	Level 1 or 2 platooning on sealed roads, all elemental conditions, with high to medium traffic

3.3 Requirements and Impacts

The outcome of the stakeholder consultation was analysed against several considerations in relation to the use cases' requirements and impacts. The considerations were obtained from the literature review and are categorised into the following groups: physical, digital, regulatory, and operations. A summary is presented below:

- **Physical requirements.** Each use case requires a different set of physical infrastructures. For instance, the automated motorway driving use case imposes no extra impact to the roads, yet the platooning use case (depending on system design and automation level) may increase rutting due to the increased number of trucks that are travelling at the same lateral position within the lane. As another example, existing platooning systems such as Peloton only allow platooning on certain road types such as dual-carriageway with non-steep grade, while current single-vehicle automation technologies would only operate on roads with appropriate line markings.
- **Digital requirements.** Similarly, each use case requires a different set of digital infrastructures. The current trend shows that single-vehicle automation technologies would rely heavily on HD maps and, consequently, precise positioning services (which may or may not be relevant to the AHV automated highway driving use case). On the other hand, the platooning use case does not inherently need positioning since the lead truck may still be manually driving. However, the platooning use case requires a low-latency V2V communication device, while Peloton also requires regular cellular connectivity to receive authorisation from the control centre.
- **Regulatory requirements.** There are some regulations that may impact both use cases, and there are some that may only impact one of the use cases. Firstly, the guidelines for trials have been laid out and the jurisdictions may use the guidelines to provide trial exemptions. Yet, it must be noted that there is no national policy on how to safely deploy these trials. Secondly, the safety management plan and insurance for the platooning operation still need some adaptation, particularly in remote and regional areas. Finally, although end-to-end post-trial regulation for AV commercial deployment is being developed, it is yet to be completed.

[20] The single AHV use case is chosen to differentiate the use case of Stakeholder A and B.

- **Operational requirements.** A particularly noteworthy operational consideration is how each use case performs in complex traffic situations. For the single-vehicle automation use case, the driver is still responsible for handling such situations at SAE Level 2 and below, whereas at Level 3 or above, the vehicle by definition should be able to handle such situations. For the platooning use case, it is imperative that an appropriate operation policy is defined for complex situations, such as intersections, on-ramps and off-ramps. During the EU Truck Platooning Challenge, the drivers intentionally disengage from the platoon when approaching on- and off-ramps due to the rules set for the trials. Yet, there is no prescriptive rule or framework that dictates this decision for commercial deployment. Thus, the drivers (in adherence to the geofencing set by the fleet operators and/or the automation system) would need to handle such dynamic situations on the road in real time, which may include: weather conditions and hazardous situations such as washouts.

The detailed analysis is presented in Table 3.3 – Table 3.6 below.

Table 3.3: Use cases' physical requirements and impacts

Physical requirement and impact	Relevance to stakeholder	
	A	B
Load capacity of infrastructure: roads, pavements, and bridges	U	Y
Increased road wear and tear	U	N
Vertical and horizontal curves limitation	U	U
Safety barriers consideration, e.g. in the platooning case	U	Y
Intersection design, e.g. CAV may allow a more compact intersection	U	N
Standards for static sign	X	N/A
'Readability' of electronic signs	X	N/A
Signs location and orientation	X	N/A
Consistent and 'readable' line marking	X	N/A
Extra maintenance required	N	U
Consistent approach for roadworks	X	N/A
Dedicated infrastructure required	N	N/A
Certain road type limitations	U	Y

Note: Y – required and available, X – required but not available, N – not required, U – as per usual, N/A – not applicable.

Table 3.4: Use cases' digital requirements and impacts

Digital requirement and impact	Relevance to stakeholder	
	A	B
Road data requirement (such as HD maps)	U	N/A
Positioning services availability (including coverage)	Y	Y
Communication services availability (including coverage of cellular network)	N	N
Clarification of data ownership	U	U
Support for proprietary digital infrastructure	N	N
Standards for data	U	U

Note: Y – required and available, X – required but not available, N – not required, U – as per usual, N/A – not applicable.

Table 3.5: Use cases' regulatory requirements and impacts

Regulatory requirement and impact	Relevance to stakeholder	
	A	B
Detailed key trial management criteria	X	Y
Appropriate insurance	X	X
Detailed safety management plan	X	X
Incidents data and information collection and accessibility	Y	Y
Digital environment regulatory framework	N	U
Cross-border approvals	N	N
Transition into commercial deployment	X	X
Fleet size and trial time limits	Y	Y
Road certification for each use case (i.e. where the use case can be deployed)	X	X
Safety monitoring systems	Y	Y

Note: Y – required and available, X – required but not available, N – not required, U – as per usual, N/A – not applicable.

Table 3.6: Use cases' operational requirements and impacts

Operational requirement and impact	Relevance to stakeholder	
	A	B
Limited ADS capability in complex traffic situations	N	Y
AHV identification (for other road users)	X	X
Automation parameter settings (such as maximum cruising speed or platooning gap)	X	Y
Driver trust and familiarity of new ADS: concern on mode transition	X	X
Extra driving challenges (e.g. lane change of a platoon requires a large gap)	X	U
[Platooning] The types, orders, and the number of AHVs in the platoon	N	Y
Limitation on certain weather conditions	Y	Y
Limitation on loads (types, size, etc)	Y	Y
Proper phasing of trials	Y	Y
Driver training on hazards that may arise due to the use of automation technologies	X	X
Detailed ConOps for operations, including safety and emergency procedures	X	Y
Public education of the use case is required for safer interactions with other road users	X	X

Note: Y – required and available, X – required but not available, N – not required, U – as per usual, N/A – not applicable.

4. Industry Expert Consultation

This section presents the outcomes of experts' engagement in the form of two webinars and an international expert peer-review process. The two webinars focused more on the platooning technology since it is deemed to be the more mature technology compared to automated highway driving (Level 3 and above).

In the first webinar held on 26 September 2017, Dr Steven Shladover from Berkeley PATH was invited to present his experience in truck platooning technology and trials. In the second webinar held on 18 December 2017, the project team and Chris Jones from Austroads presented the literature findings and the learnings from the 2017 ITS World Congress. Attendees of these webinars included Mathew Fogg (MRWA), Chris Jones (VicRoads) Darwin Zeta (ACT), Kym Foster (ALGA), Russell Yarrow (TMR) Lillia Rozaklis (DPTI SA) Andrew Poole (StateGrowth), Richard Yeo (Austroads), David Bobbermen (Austroads), Neil Wong (NTC) and Greg Forbes (Austroads industry reference group). Finally, the report was peer reviewed by international experts, namely Dr Richard Bishop (Bishop Consulting) and Dr Steve Shladover (PATH Berkeley).

4.1 Implementation Considerations for Australia

There are several key considerations for Australia that were identified from the discussions with local experts, namely regulatory barriers to platooning (i.e. following distance law), platooning authorisation/accreditation, and a truck platooning roadmap for Australia.

4.1.1 Road Rules

As identified in the literature review, the following distance law has been identified as a potential barrier in deployment of AHVs, in particular the platooning use case. Dr Shladover pointed out that truck platooning technology allows a following distance of as close as 4 metres, while a 15+ metre gap is expected to be the approach for typical commercial operations. However, the current regulation specifies a considerably longer distance (of 200 m or 60 m for non-road train long vehicles). This is a great barrier to platooning deployment in remote areas since the majority of vehicle configuration in remote and regional areas is long vehicle, and the fuel savings benefit is more pronounced at closer following distance. Therefore, the regulation would have to be adjusted to accommodate efficient platooning operations.

Additionally, concerns were raised when Level 1 platooning is performed on unsealed and corrugated roads. Since the following driver still has to steer the vehicle, a dusty environment and vibration might pose a challenge. This point relates to Section 4.1.2 below on platooning access/authorisation.

4.1.2 Platooning Access and Authorisation

Current platooning technology providers authorise platooning only in specific ODD due to safety concerns (for instance, Peloton utilises their control centre to authorise platoons). This raises a concern on how to regulate platoon operations[21], which should consider, but not be limited to:

- location in the road network (e.g. dual/single carriageway, bridges, narrow lanes, steep grades, surface)
- time of day (e.g. lighting condition, traffic condition)
- weather (e.g. heavy rain, flooding)
- vehicle and technology (e.g. load mass, vehicle combination, brake specifications, driver training).

[21] May be handled by drivers on the road.

For instance, the control centre will continually receive updates on weather conditions and will be able to cease the platooning operation if a washout has been discovered.

A few options of authorisation models were discussed:

- **PBS-like central assessment scheme.** In this option, a regulatory body defines a set of criteria for platoon formation. Each time a platoon formation is requested, a control centre assesses and approves the request based on the criteria. In this option, the road agencies may assume the role of the control centre, which will allow them to better manage the risk and communication of truck platooning deployment. However, on the other hand, this might be too complex to put into practice and could create confusion among the fleet operators as has the PBS scheme.
- **Accredited platoon operators.** In this option, there are some platoon operators that have been approved by an accreditation body to operate platooning. Each pair of trucks that wants to perform a platoon would send an authorisation request to one of these accredited platoon operators[22]. In this option, the road agencies would still play a role in communicating relevant and necessary information to the platoon operators, such as weather conditions, washouts, roads closure, and real-time traffic information. Obviously, the fleet operators themselves can become the platoon operators.
- **Standardisation of use case.** Another option is to prescribe a set of standard use cases (within a standards-like document) for which platooning may happen. For instance, truck platooning can only be carried out on: multi-lane dual-carriageway, and not on weaker bridges. Given the large number of possible scenarios under which platoons may operate, this option is not an ideal long-term solution, yet it may be a short-term solution that assists in accelerating the deployment of platooning.

4.1.3 Data Centre and Vehicle Tracking

The concept of a control/data centre might play a key role in managing AHVs in remote and regional areas. For instance, a truck platoon may communicate with the data centre to determine whether the current road is suitable for truck platooning (if not already handled by drivers). Additionally, vehicle tracking will aid to monitor breakdowns and incidents (likely done by satellite communication).

4.1.4 Use Case of Single AHV Operation

The automated highway driving use case covers quite a wide range of various options for trials, including: pit to port/depot to depot, last mile automation for loading/unloading, with the eventual goal to achieve automated highway driving with mixed traffic.

4.1.5 Heavy Vehicle Modification Market

It is worth noting that Australia has a significant heavy vehicle modification market, with many vehicles sold incomplete with second stage and aftermarket modification to complete the vehicle. This could be an issue if a use case requires highly sophisticated messages that need to know the exact length of a vehicle to properly configure the braking signal. For instance, a prime-mover could be adapted to be a B-double one day and a 19-metre articulated vehicle on another day.

4.1.6 Australian Platooning Roadmap

Considering the rapid development and commercialisation of platooning technology, Australia needs a strategic approach to efficiently and safely bring this technology into the market. Learning from EU, Australia will benefit from learning and appropriately adapting/revising the ACEA platooning roadmap (shown in Figure 2.1). A roadmap will provide a clear goal and a holistic (national) view of the progressive steps that need to be taken to achieve the goal.

Some suggestions that may be included in the roadmap are:

[22] Note that platoon formation is still handled by the drivers on the road. The platoon operators would only provide authorisation, as in the Peloton case.

- **Trials.** There have been many truck platooning trials in EU and the USA. The roadmap may help us in determining the extent of trials that need to be done to adjust the platooning technology to suit Australian conditions. It also helps in preventing trials duplication across different states.
- **Complementary initiatives.** By producing the roadmap, it will be easier to determine the required or complementary initiatives to achieve the goal. For instance, a suggestion was made to introduce a mechanism for road surveying for CAV operations. This aligns with the need to better inform where platooning (or AHVs) in general may/could operate, while at the same time, it is an initiative that helps road operators/owners to better maintain their road networks.

4.2 Views from International Experts

International experts Dr Richard Bishop (Bishop Consulting) and Prof Steve Shladover (PATH Berkeley) were invited to conduct a peer review of this research report. The peer review was completed in conjunction with the project reference group review process. Based on the comments received, each of the sections in which feedback was provided were updated, and in addition, the following subsections were added. The comments from the international experts that contained new information or that were not specific to a section of the report were collated and are summarised in the nine categories listed below.

4.2.1 On Cellular Connectivity Requirements

A finding of the literature was that cellular connectivity is a requirement for Level 2 platooning; however, the international experts believed this not to be the case. The reason being that the key component of a platooning system lies within its on-board equipment and direct V2V communication. Thus, although it provides additional robustness, cellular connection is not a necessity. Furthermore, it was also suggested that there are other means to achieve the intended purpose of the operation centre, which is to geofence the platooning operation. For instance, a satellite connection can be used (although costlier) and/or authorisation could be extended to hours or a full day. Additionally, geofencing doesn't necessarily need cellular connectivity as per Peloton's model, yet it can be achieved through internal system mapping which can disable automated mode when it is outside the pre-defined boundaries.

In addition to comments about cellular connectivity requirements it was highlighted that although the Peloton platooning deployment model is a leading example in this area, the Peloton requirements are unique to Peloton as a commercial entity and should not be considered as a general requirement for other truck platoon systems.

4.2.2 On Geofencing and Managing Access

The experts described the system for managing geofencing and access conditions as likely to be based on either a network operations centre (NOC) or existing fleet management systems. The system can be managed directly by the OEM, fleet operator, or a service provider such as Peloton without the need for direct involvement of the government. The role of government need not be directly involved in the operation of heavy vehicle configurations and platoons but rather in providing safety oversight. The expert suggests that the major truck manufacturers are all developing platooning systems, with the intention to sell those to their customers as products rather than services. It is expected that transport operators will continue to buy and operate vehicles as they do today and manage the AHV operations via their existing fleet management systems. This view is consistent with the views of transport operators expressed during the industry consultation.

The transport operators will be able to decide where on the road network, which drivers and what vehicles should operate in an automated mode or platoon but will be limited by the conditions of the ODD. The ODD will be defined by manufacturers imposing restrictions on when the operation of an automated feature is not trusted to be safe. The monitoring of road and weather conditions, for example, via sensors and the operation of lights, wind screen wipers and DSM can contribute to the system operation. The alternative business model is based on these same services being provided by a third party via a cellular connected NOC.

In the case of any locations where the platooning should be restricted due to specific infrastructure requirements, road managers can notify the system providers and provide the necessary map information for geofencing. Regarding the common concerns of platooning and bridge loading (discussed further in Section 4.2.4), the same approach can be used where the ODD is set up to exclude the restricted bridges.

4.2.3 On Digital Infrastructure Requirements

It was agreed that obtaining precise positioning services and other digital infrastructure is a challenge for AHV operations in remote and regional areas. However, it is not certain that precise positioning is required for Level 3 automation in remote and rural environments as vehicle sensors can detect line markings, edge lines and road signs; this is sufficient to provide guidance information for a vehicle automation system. If a GPS signal can be received (providing 10 m accuracy) it should be possible to reference the vehicle location to a digital map. This will be sufficient to provide information about the location of intersections or locations where extra caution is needed and potentially vehicle control returned to the driver. In the case of brief losses in GPS signal, these can be overcome by systems integrated with inertial navigation system (INS). This can be complemented by on-board units such as radar, video, and wheel speed.

Precise positioning for the relative positions of the trucks within a platoon is not required either; this is monitored by other means including radar and video combined with wheel speed data.

There have been concerns that the lack of augmented satellite positioning plus the need for HD maps is a key deployment barrier for AHVs in remote regions; however, an expert suggests that with current technology, navigation in remote areas can be achieved by appropriate relevant lane/road markings, a modestly enhanced map (with radius, grade, lateral slope, speed limit) and INS dead reckoning to combat brief losses of GPS signal. This is supported by the fact that current commercial activity does not rely on augmented satellite positioning or HD maps for automated truck highway driving.

4.2.4 On Physical Infrastructure Impact and Requirements

Regarding concerns related to bridge loading due to platooning vehicles following in close succession, it has been pointed out that the possible cause of these concerns is not due to any increase in static loading (as the heavy vehicle mass remains unchanged) but rather the dynamic loading related to the (short) axle separation distances. An expert suggests (based on US views, vehicles, and infrastructure) that this was not considered to be an issue if the separation is such that the loading frequency does not correspond to a structural resonance frequency. As such, a simple fix is to specify the gaps between trucks in a platoon to break up the periodic pattern of loading. It is outside of the scope of this research, but an investigation into the currently permitted axle spacing compared with those likely to result from platooning would lead to a better understanding of the impacts on bridges. Moreover, geofencing may be implemented to increase the gap between platoons when crossing vulnerable bridges.

Similarly, pavement rutting concerns are not considered by the international experts as an issue since it can be addressed simply by adding dither to the lateral position of the trucks in the platoon. Further, note that this issue only arises for Level 2 followers or above, whereas existing technology such as Peloton generally only allows Level 1 followers for which impacts on rutting would not be different from current heavy vehicle operation.

4.2.5 On Platooning Operations

Regarding the platooning vehicles approaching complex situations such as intersections that may require decoupling to ensure safe operation, the expert review highlighted the importance of the role of the lead driver. In these instances, the onus is on the lead driver to decide when to disengage the platoon. Additionally, it has been found from KONVOI trials in Germany that vehicles would still cut in between two semi-trailers when in platoon formation with a 10 m gap. Current generations of platooning systems include sensors that detect vehicles approaching and respond by increasing the following gap, rather than fully disengaging the platoon, then closing the gap when the vehicle has left. This is an essential feature of the platoon control system. It should also be noted that outcomes of European trials were based on highways with on- and off-ramps that are typically closer together than those in Australia, thus allowing less merging lane distances. The international experts cited test track experiments conducted in the USA that have shown that cut-ins as frequent as one in every 3.2 km produced only 1% fuel savings.

Another important consideration is the operational differences between trials and commercial deployment. In trials, a conservative approach is usually adopted, including reduced speed and gaps that are wider than what the platooning system can deliver. This may lead to outcomes unique to trials such as confusing other drivers (uncertain whether the trucks are in platoon or manually driven), thus leading to increased overtaking. The findings from the European Truck Platooning Challenge highlighted as relevant were:

1. **Overtaking**: Some truck drivers reported observing that road users (car and truck drivers) were more reluctant to pass and took longer to decide on passing. Occasionally, single truck drivers would abort the overtaking manoeuvre when they realized the full length of the platoon. In contrast, other drivers observed more passing manoeuvres, especially by trucks. Platooning drivers observed that single truck drivers were frustrated about how long it took to get by the full length of the platoon.
2. **Merging**: Truck drivers noted that platooning with a required following distance of 0.8 seconds (18 metres at 80 km/h) seemed to confuse drivers of single trucks. In these cases, there appears to be room to initiate a merge, with the expectation that the trucks in the target lane would widen the gap (typical driver etiquette); but of course, the platooned trucks (under automated longitudinal control) did not do so. The drivers noted that when platooning at 0.5 seconds (11 metres at 80 km/h) headway, the situation is clearer for drivers of single trucks.
3. **Speed differentials**: Speed was observed to be a determining factor in the number of passing manoeuvres. If the speed of platooning trucks roughly matches the typical speeds of other trucks, there is much less motivation to pass. The European Truck Platooning Challenge imposed a rule to limit platooning speeds to 80 km/h; this disrupted traffic flow and caused single trucks to initiate passing. This caused ‘substantially more overtaking manoeuvres by other trucks than would be the case if the truck platoons were driving more in accordance with the actual driving speed of normal single trucks’. In fact, in Belgium – where the maximum speed is 90 km/h – passing manoeuvres were less frequent.

There are several other topics brought up by the experts relevant to platooning. Firstly, the lowest performance truck needs to be leading for safety reasons. Alternatively, the NOC (such as in the Peloton model) may enforce the braking capability to follow the weakest one. The following order and minimum following distance should be selected based on ensuring that all vehicles in the platoon can avoid or at least limit the severity of rear-end crashes in emergency conditions.

Secondly, the concern of mixed traffic could be handled by artificial isolations of AHV operations, such as a time of day restriction, or special closure when AHVs are in operation (feasible only in remote areas where there is almost no other traffic). Thirdly, it has been suggested that operational standardisation and interoperability is a business issue that will arise when the market demands it.

4.2.6 On Technology Advancement

It has been pointed out that new generations of platooning technology will be able to detect vehicle cut-ins and widen the gap, while still passively in platoon, until the vehicle leaves. Coupled with the discussions on the operational issues above, the experts agree that platooning poses no major safety concerns that would be prohibitive to its implementation. However, this would add additional challenges to the community safety perception of heavy vehicles.

The need for detailed digital maps has been discussed and in the context of remote and rural regions of Australia and New Zealand it is likely that digital maps will not be updated as frequently as metropolitan areas. If heavy vehicles are to be operated on roads that are not on existing digital maps, the cost of mapping those roads should be modest compared to the costs of making physical infrastructure modifications.

Regarding the challenge of operating AHVs amongst a mixed fleet (i.e. with vehicles with no automated driving systems), the expert suggests that this is not a technical issue nor a government issue, but rather a business issue. It is believed that solutions will not need to be offered for first generation platooning but will come later, based on customer demand, and it is not significantly challenging on a technical level.

The greater challenge was considered to be developing the methods of engineering the software systems on Level 3 and 4 vehicles so that their failure rates can be lower than the failure rates of human drivers today and then demonstrating that these failure rates have actually been achieved.

4.2.7 On Human Factors Consideration

The experts suggest that a good HMI increases safety and reduces the training effort. The HMI should quickly capture the attention of a driver, particularly for Level 2 operations and above where drivers have become disengaged from driving tasks. Secondly, a sufficiently intuitive HMI will reduce the driver training effort. Evidence supporting this comes from naïve subject experiments conducted during track testing in which a CACC system on three trucks were introduced to nine truck drivers, with about 15 minutes of pre-driving explanation and about a half hour of on-road instruction by one of our staff members for each of the new drivers. Truck driving instructors were asked how long they would expect a new driver to need to become fully familiar with the system, and their general conclusion was that it would take no more than one day of driving.

However, the lead driver role requires more experience to make safety-related decisions, such as when encountering complex situations. Additionally, lead driver experience helps in building trust among the followers.

DSM was deemed unnecessary for Level 1 vehicle or platooning operations with a large gap (greater than 20 m). Based on the expert's discussion with Peloton, drivers following at approximately 12 m still faced no problem regarding visual occlusion.

The expert review introduced the importance of notifying other road users of the presence of platooning vehicles (e.g. using distinct decals). Consideration should include the purpose of notification, the differentiation of SAE levels, and the special consideration for enforcement personnel. So far notification has not been required by state regulators in the USA, but it is an active topic of discussion within the Commercial Vehicle Safety Alliance with operators planning to mark equipped tractors with distinct decals. There are also plans at work in the USA for the state departments to issue educational information to the public and other stakeholders.

4.2.8 On Risk and Regulation

The importance of risk management was raised by both experts, particularly for higher levels of automation. This should not be much of a concern for the lower levels of automation, but it is a more significant issue for Level 3 and above, where the safety of the system depends entirely on its technology rather than on the skill of the driver. As with adopting a Safe Systems approach, the assumption must be that the technology will fail at some point. Therefore, the decision-makers (road agencies and regulators) should determine their level of tolerance of the risks associated with technology failure. This involves answering questions about whether the officials can accept responsibility and assure the public that they have done their due diligence to sufficiently protect the public against adverse events such as if an AHV:

- runs off the road and its spilled load pollutes a local water way
- runs off the road damaging third party property
- hits an illegally parked vehicle, injuring or killing its occupants

- strikes and kills a hitchhiker on the roadside
- hits a vehicle that was stalled in an intersection, killing its occupants.

The events on the list that are considered unacceptable risks can provide guidance about which kinds of interactions between the automated trucks (or platoons of heavy vehicles) and other road users must be avoided by implementing operational and/or legal measures to prohibit their occurrence, such as segregating them physically.

Additionally, as part of the risk management/safety assurance system, the California Department of Motor Vehicles (DMV) model can be adopted, whereby OEMs need to provide trial data to demonstrate the safety of their products. Similarly, the safety assurance model proposed by the NTC can be used, which is self-certification with an auditing agency.

4.2.9 On Benefits of Automation

It is suggested that Level 3 automated highway driving is the main opportunity for remote and regional areas in Australia and New Zealand. The main benefits of automation are through the reduction of labour costs, as technology is not ready to remove drivers completely from the cabin. The labour cost savings that become possible when drivers are not required in (at least some of) the heavy vehicles is significant and a motivating factor for industry to adopt lower levels of automation with this long-term view. However, it is highly uncertain in timing, especially based on the considerable technological challenges that must first be met.

Additionally, the potential safety benefits of Level 2 may be typically overestimated. Level 1 automation is most likely to improve safety because it requires the driver to remain fully engaged in the driving task, while augmenting the driver’s vigilance. At Levels 2 and 3 there should be consideration of the risks of driver inattentiveness and disengagement, drivers may be inclined to over-trust the system and not pay as much attention as they should to the driving task. Mitigating these risks will require close oversight as these systems become available, and the designs of their driver interfaces will be critically important to ensuring safety. When the driver is no longer engaged in the driving task (temporarily at Level 3, for more sustained periods at Level 4), the safety of the vehicle becomes entirely dependent on the ADS, and the technology does not exist yet to provide safety assurance. Further work is required to determine the safety benefits of Level 2 and above, which may include verification of the ADAS software and functionality or demonstration through trials or performance testing.

4.3 Overview of Opportunities and Barriers

Further discussions with key stakeholders and international experts have cemented the findings that have been discussed throughout the report. Here, an overview of the opportunities and barriers for each of the identified use cases is presented in Table 4.1 –Table 4.3. This overview provides a holistic view of the opportunities and barriers, and acts as a tool to systematically plan future works and projects.

Table 4.1: Single AHV motorway deployment analysis

Single AHV – on-ramp to off-ramp operation				
	SAE Level 1	**SAE Level 2**	**SAE Level 3**	**SAE Level 4**
Key enabling function	LKA	ACC + LKA	L3 ADS	L4 ADS
Benefits	Safety (carriageway departure crash), driver workload	Safety (carriageway departure and rear-end crash), driver workload	Safety, driver workload, productivity	Safety, driver workload, productivity, labour cost savings
Highly automated vehicle (HAV) laws applicable	No	No	Yes	Yes
Communication protocols for C-ITS platoon message	No	No	No	No
High quality lane markings	Yes	Yes	Yes	Yes
Digital: High quality signs/HD maps with key road data attributes	No	No	Likely	Likely
Following distance law barrier	N/A	N/A	N/A	N/A
Mobile coverage	No	No	Likely	Likely
Bridge assessment/ pavement issue	No	No	No	No
ODD limiting issues	Line marking	Line marking	Line marking, HD maps with key road attribute data, HAV laws	Line marking, HD maps with key road attribute data, HAV laws
Could it be deployed now?	Yes	Yes	No	No
What would be required to allow broad ODD?	Line marking included where not available	Line marking included where not available	• Reform of HAV laws • Line marking • Cellular network coverage • Road data attributes	• Reform of HAV laws • Line marking • Cellular network coverage • Road data attributes • Extensive technology development

Table 4.2: Time-based platooning deployment analysis

Platooning – time-based following (large gap)				
	SAE Level 1	**SAE Level 2**	**SAE Level 3**	**SAE Level 4**
Key enabling function	CACC, platooning system, low-latency V2V	CACC + LKA, platooning system, low-latency V2V	CACC + L3 ADS, platooning system, low-latency V2V, potentially cellular comm	CACC + L4 ADS, platooning system, low-latency V2V, potentially cellular comm, safety assurance methods
Benefits	Reduced workload, some fuel savings at 60 m for trailing vehicle	Reduced workload, some fuel savings at 60 m for trailing vehicle, safety (carriageway departure crash)	Reduced workload, some fuel savings, safety, productivity	Reduced workload, some fuel savings, safety, productivity, potential labour cost saving
Highly automated vehicle (HAV) laws applicable	No	No	Yes	Yes
Communication protocols for V2V platoon message	Yes (except for first generation prototype)	Yes	Yes	Yes
High quality lane markings	No	Yes	Yes	Yes
Digital: High quality signs/HD maps with key road data attributes	No	No	Unclear	Unclear
Following distance law barrier	No above 60 m or 2.2 s	No above 60 m or 2.2 s	No above 60 m or 2.2 s	No above 60 m or 2.2 s
Mobile coverage	Doubtful	Doubtful	Probably yes	Probably yes
Bridge assessment/ pavement issue	No	No	No	No
ODD limiting issues	Multiple carriageway only	Multiple carriageway only, high-quality lane marking	Multiple carriageway only, high-quality lane marking, may require HD maps with key road attributes	Multiple carriageway only, high-quality lane marking, may require HD maps with key road attributes
Could it be deployed now?	Yes	Yes	No	No
What would be required to allow broad ODD?	Regulatory framework for safety assurance	• Regulatory framework for safety assurance • Lane markings where not available	• Regulatory framework for safety assurance • Lane markings where not available • Potentially new data required to support platooning • Reform HAV laws to allow following vehicles to operate without driver (NTC work program)	

Table 4.3: Distance-based platooning deployment analysis

Platooning – distance-based following (narrow gap approx. at 20 m)				
	SAE Level L1 – L1	**SAE Level L1 – L2**	**SAE Level L1 – L3**	**SAE Level L1 – L4**
Key enabling function	CACC, platooning system, low-latency V2V	CACC + LKA, platooning system, low-latency V2V	CACC + L3 ADS, platooning system, low-latency V2V, potentially cellular comm	CACC + L4 ADS, platooning system, low-latency V2V, potentially cellular comm, safety assurance methods
Benefits	Fuel efficiency	Fuel efficiency, safety (carriageway departure crash)	Fuel efficiency, safety, productivity	Fuel efficiency, safety, productivity, potential labour cost savings
Highly automated vehicle (HAV) laws applicable	No	No	Yes	Yes
Communication protocols for V2V platoon message	Yes	Yes	Yes	Yes
High quality lane markings	No	Yes	Yes	Yes
Digital: High quality signs/HD maps with key road data attributes	Possibly	Possibly	Likely	Likely
Following distance law barrier	Yes at 60 metres or 2.2 seconds separation	Yes at 60 metres or 2.2 seconds separation	Yes at 60 metres or 2.2 seconds separation	Yes at 60 metres or 2.2 seconds separation
Mobile coverage	Doubtful	Doubtful	Probably yes	Probably yes
Bridge assessment/ pavement issue	Potentially	Potentially	Potentially	Potentially
ODD limiting issues	Multiple carriageway only, bridge assessment required	Multiple carriageway only, high-quality lane markings, bridge assessment required	Multiple carriageway only, high-quality lane markings, bridge assessment required, may require HD mappings with key road attributes	Multiple carriageway only, high-quality lane markings, bridge assessment required, may require HD mappings with key road attributes
Could it be deployed now?	Yes within limited ODD	Yes within limited ODD	No	No
What would be required to allow broad ODD?	• Determine when platooning is safe, and under what conditions. New regulatory framework needed • Standards for exchange of platooning messages may be required for C-ITS • Determine if asset assessment is needed, or if network should be restricted • Line marking on routes where not available (Level 2) • Bridge assessment/route approval		• Same as before Level 1 and Level 2 • Potentially new data required to support platooning • Reform HAV laws to allow following vehicles to operate without drivers (NTC work program)	

5. Conclusions

This section concludes the report by outlining the lessons learned and providing an implementation roadmap. The lessons learned summarise the key findings in this project and can be categorised into four groups, namely technology, infrastructure, regulation, and opportunities in remote areas. Furthermore, the implementation roadmap is derived based on the learnings from Table 4.1 – Table 4.3.

In summary, there are two opportunities for AHV deployment in remote and regional areas, namely automated highway driving and truck platooning. Automated highway driving is concerned with single vehicle automation, whereas truck platooning considers multi-vehicle automation of the following trucks (the lead truck can either be manual or automated). The benefits of automation include safety, efficiency, productivity, fuel savings, and to a certain extent, some social aspects.

The fleet operators are ready for deployment of AHVs, with a focus of gaining increased efficiency in their operations (reduced labour costs, increased fuel efficiency). Despite the initial impression that the physical and digital infrastructure are lacking in the remote and regional areas to support deployment of AHVs, it has been clarified by the international experts that this is not the case, as technology will eventually be developed to operate through these perceived barriers. However, there are still some regulatory barriers, such as following distance law, that might hinder the adoption of these automation technologies in Australia and New Zealand. As such, it is proposed that a systematic approach to overcome these challenges is taken, which results in an implementation roadmap of AHVs in Australia and New Zealand.

This project has delivered its intended goals as follows. Firstly, the literature review, industry and expert consultations carried out have provided enough information to enable government to begin work on readying their networks of AHVs in remote areas. The report has taken a step further to propose an implementation roadmap (shown in Section 5.2 below) to help guide the government's actions. Secondly, the stakeholder consultation has enabled the freight industry to explore the options provided by new automation technology for heavy vehicles. Thirdly, the literature review, along with the stakeholder consultation, has shed a light on the best ways to deploy AHVs in remote and regional areas. Finally, the industry expert consultation has identified the regulatory, policy, and infrastructure critical issues pertaining to AHVs in remote areas, which need to be addressed in a timely manner.

5.1 Lessons Learned

The lessons learned are placed into three categories: technology, infrastructure, and regulatory.

5.1.1 Technology

- In Australia, single-vehicle automation at SAE Level 3 is deemed to be more useful compared to platooning, since Australia allows mechanical coupling/platooning[23]. The benefits are more obvious and industry is more readily willing to adopt this technology when available. However, the technology itself is not ready and its development depends on the OEM.
- Precise positioning may be required for single vehicle automation at Levels 3 or 4. Precise positioning can be achieved via several methods, such as SBAS, real-time kinematic correction, and dead reckoning (inertial navigation systems), in addition to various OBUs.
- Platooning configuration is an important aspect when considering deployment, since it significantly affects the requirements. The platooning configuration outlines the SAE levels of the leader and, more importantly, of the follower.

[23] The comparison between road trains vs. platooning is not immediately obvious and needs further investigation.

- Existing platooning systems have two approaches to adjust the following gap, namely time-based and distance-based. The latter poses more implementation challenges since it has smaller margin for error if it is implemented at very short gaps.
- ODD limitation is important yet is expected to be handled by the OEMs or the fleet operators (i.e. self-certification with an auditing model). For instance, Peloton platooning system relies on a central control centre to authorise platoon formation. This is important to ensure that platoons are formed within the prescribed ODD limitation.
- It has been identified from overseas literature that interoperability of platooning systems is very beneficial to the future deployment.
- DSM may play an important role in the safety deployment of AHVs at SAE Level 2 or higher in remote and regional areas, to assist in handling fatigue and distractions.

5.1.2 Infrastructure

- Australian and New Zealand roads in remote and regional areas are not ready for AHV deployment. Firstly, single vehicle automation needs lane markings on both sides, while shoulders are possibly needed for safety. Secondly, standardisation of signs and road operations are lacking, as is the challenge faced by general CAV. Finally, the prescribed ODD of a truck platooning system is likely only allowed in dual-carriageways currently, which does not fit the majority of remote streetscapes.
- Connectivity in remote and regional areas is a challenge, whereas it may be required by some platooning systems.
- Additionally, a precise positioning service is generally not available in remote and regional areas. The need for this depends on the system implementation approach.

5.1.3 Regulation

- Following distance rules in Australia and New Zealand may hamper the deployment of platooning.
- Lack of a 'hands-free' rule[24] may partially negate the potential benefits of Level 3 AHVs.
- The recently released ITS class licence removes one of the regulatory barriers for implementation.
- A major question that still needs to be addressed is platooning accreditation and access process – What is the most efficient method?
- Operation: The operation of platooning around on-ramp and off-ramp, and complex infrastructure in general needs to be considered. Although dynamic situations are likely to be handled by the drivers on the road (with guidance from road operators), geofencing (such as on weaker bridges) can be achieved via ODD limitation either through an on-board map system or through a control centre.
- Operation: Interaction with other road users, including vulnerable road users (VRUs), and infrastructure needs to be thoroughly explored particularly for the platooning use case. For instance, decoupling of platoons may be necessary (in earlier prototypes) when other vehicles are wanting to cut in (say, to exit a motorway). The various risks and scenarios that may be encountered need to be assessed, which then can be used as a guideline on ODD and deployment planning.

5.1.4 Opportunities in Remote Areas

- Through the stakeholder consultation process, it is deemed that the Australian heavy vehicle industry is ready for deployment of AHVs. The interviewees indicate that their companies can already see the benefits from both the single vehicle and platooning use case.
- The road environment in New Zealand differs from Australia and there are not sufficiently sustained remote settings, where the risks from and to other traffic are considered to be sufficiently low.
- The opportunity of interest from each company varies depending on their operations. Thus, further industry consultation is necessary to determine appropriate prioritisation of use cases.

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[24] This includes the fact that the driver should remain ready to take over control.

5.2 Implementation Roadmap

Table 5.1 shows an implementation roadmap, derived from the lessons learned. This serves as the recommendation of this report.

Table 5.1: A recommended implementation roadmap for AHV deployment in remote and regional areas

Timeline	Policy	Infrastructure	Technology
Short-term (preparation)	• Following distance rule • Hands-free driving rule • AHV accreditation and access	• Line marking specs update for CAV • Digital infrastructure strategic areas to deploy	• Establish WG to collaborate with OEMs and technology developers • Discuss digital infrastructure requirement (control centre, type of technology)
Medium-term (implementation & further refinement)	• Broadening of ODD • Complementary equipment regulation (e.g. DSM) applied carefully to specific levels and use cases • Interoperability-related policy • CAV commercialisation regulatory options	• Line marking upgrade • Digital infrastructure deployment • HD maps provision • Establish control centre (if applicable)	• Discuss white layer architecture (operated by govt) to allow interoperability based on feedback from industry
Long-term (commercialisation)	• Refine any other specific operational regulations • Implement CAV commercialisation regulations	• White layer (for interoperability) set up	• Collaborate with OEMs to encourage uptake of CAV

As can be seen, the implementation roadmap caters for both opportunities, the single AHV and platooning use cases. Furthermore, the roadmap consists of short, medium, and long-term action plans that help illustrate the sequential requirements for both use cases. Note that the roadmap is intended for road operators and, as such, excludes the action plan related to OEMs (such as technology development).

Out of the three categories in the roadmap, the infrastructure category provides the biggest challenge as it requires the highest time and capital investments compared to the others. The government should keep collaborating with the OEMs to discuss the specifications of infrastructure requirements (both physical and digital). However, international experts suggest that the technology developers and truck OEMs are continually developing their technology without expecting any support from the governments and/or road operators. Thus, the infrastructure category (along with the short-term tasks in the technology category) can be seen as the critical path that requires urgent attention to prevent any delays of commercial deployment of AHVs in remote and regional areas.

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Glossary and Abbreviations

Terminology/Acronym	Description
3G	Third Generation of Mobile Telecommunications
4G	Fourth Generation of Mobile Telecommunications
5G	Fifth Generation of Mobile Telecommunications
AAS	Mercedes-Benz Attention Assist System
ABS	Antilock Braking System
ACC	Adaptive Cruise Control
ADAS	Advanced Driver Assistance System
ADS	Automated Driving System
AHV	Automated Heavy Vehicle
AV	Automated Vehicle
CACC	Cooperative Adaptive Cruise Control
CAV	Connected Automated Vehicle
C-ITS	Cooperative Intelligent Transport Systems
ConOps	Concept of Operations
DAC	Volvo’s Driver Alert Control
DAS	Driving Automation System
DAWS	Saab’s Driver Attention Warning System
DDT	Dynamic Driving Task
DMS	Toyota’s Driver Monitoring System
DSM	Driver State Monitoring
DSRC	Dedicated Short Range Communication
ESC	Electronic Stability Control
EBS	Electronic Braking Systems
GPS	Global Positioning System
GNSS	Global Navigation Satellite System
HMI	Human Machine Interface
ITS	Intelligent Transport Systems
LCA	Lane Centering Assist
LiDAR	Light Detection and Ranging
LKA	Lane Keeping Assist
OEM	Original Equipment Manufacturer
RSP	Rollover Stability Program
SBAS	Space Based Augmentation System
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
V2X	Vehicle to External Environment

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