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Parliamentary Inquiry
Monash University
Submission 2

Current and future developments in the use of automation and new energy sources in land-based mass transit

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FOREWORD

The following contribution from the Monash University Accident Research Centre (MUARC) aims to address the parliamentary inquiry related to the current and future developments of automation of land-based mass-transit vehicles. Given that the expertise of MUARC is primarily in the safety of on-road vehicles and road infrastructure, the scope of this report is limited to autonomous mass-transit buses and shuttles. Due to the lack of peer-reviewed literature in this area, the knowledge shared in this review has been drawn from literature related to autonomous passenger vehicles and the expert knowledge of the research team. Both peer-reviewed and grey literature was sourced in the formulation of this review.

The following document discusses in detail the current state of mass-transit vehicles including briefly, the specifications of the currently available mass-transit shuttles and where they operate. The future developments related to autonomous mass-transit vehicle use is discussed. In addressing current and future developments, the likely interaction that these vehicles will have with conventional vehicles or partially autonomous vehicles and vulnerable road users is also covered. The safety concerns related to passengers aboard these vehicles is reviewed and recommendations are provided for more stringent monitoring of the crashworthiness of the autonomous mass-transit vehicles, with a recommendation for a dedicated authority/regulatory body to oversee the safety and reliability of autonomous mass-transit vehicles and their interaction with road users now and the foreseeable future.

This submission should be read in conjunction with the broader submission from Monash University (Submission 1).

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1 INTRODUCTION

Autonomous mass-transit vehicles refer to fully-automated vehicles that are capable of safely transporting groups of fee-paying individuals from one destination to another destination while successfully handling interactions with other vehicles and road users. These include trains, boats, buses, shuttles and passenger vans and/or minivans. While air-, water- and rail-based autonomous mass-transit vehicles are currently in operation and significant developments are underway to integrate these vehicles into the transportation system, these will not be discussed here. The focus herein will only be on safety issues related to autonomous shuttle vans and buses.

The following is a brief review regarding safety issues that are likely to be of concern as autonomous mass-transit vehicles such as shuttles, passenger vans and buses are introduced onto open roads and will need to integrate with non-automated vehicles, partially or fully automated passenger cars, vulnerable road users, two-wheeled vehicles, and existing roads and infrastructure. Due to the novelty of autonomous technology related to mass-transit vehicles, there is at present limited literature pertaining to the safety implications of these vehicles. Unless otherwise specified, the following text has been formulated based on the authors' views and by applying and extending the current knowledge of autonomous vehicles in general to autonomous mass-transit vehicles.

Case study

On the 8th Nov, 2017, the French owned Navya 'Arma' - an autonomous and electric shuttle bus operated by Keolis North America, began its first service in Las Vegas. It was intended to ferry up to 15 passengers at a time in a half-mile loop around the Fremont Street Entertainment District (along the famous 'Las Vegas Strip'). The vehicle was fitted with lap belts for passengers (Marshall 2017). Only a few hours after commencing operation, a delivery truck backed into the stationary shuttle. There were eight passengers on board the shuttle bus at the time of the incident. The front end of the shuttle sustained minor damage as a result of the impact, including a crumpled front fender and damaged sensor. No passengers were injured. The Navya Arma was repaired and returned to service the following day.

Leading to and during the collision, the shuttle did nothing later deemed incorrect. It detected the truck approaching towards it and stopped. It remained stationary until the truck backed into it.

Reporter Jeff Zurschmeide, who was on the shuttle at the time of the crash, said, "The self-driving vehicle did what it was programmed to do, but not everything a human driver might do" (Shepardson 2017). According to passengers on the shuttle at the time of the crash, there was approximately 20 feet of empty street behind the shuttle. Instead of attempting to reverse the vehicle or sounding the horn to make the vehicle's presence known to the reversing truck, the shuttle did nothing. A spokesperson for the City of Las Vegas who commented on the crash similarly noted, "The shuttle did what it was supposed to do and stopped. Unfortunately, the human element, the driver of the truck, didn't stop." According to a Keolis representative, the shuttle had the ability to sound its horn but didn't in this instance because the trailer of the truck backing into the shuttle moved in a way that the autonomous vehicle did not anticipate (Marshall 2017).

This real-world incident is consistent with data that highlights the trend that autonomous vehicles currently penetrating the international road network are not fully equipped to overcome the limitations associated with human drivers in control of conventional vehicles (Lambert 2017). That is, the majority of crashes involving autonomous vehicles, including the case involving the Navya Arma autonomous shuttle, are the fault of 'the other human driver' in the conventional vehicle. Given this, it is timely that a Parliamentary Enquiry be held into safety surrounding the performance and integration of autonomous mass-transit vehicles into a fleet of conventional vehicles including conventional mass-transit vehicles.

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2 CURRENT STATE OF AUTOMATED MASS-TRANSIT VEHICLES

The momentum behind developing fully autonomous passenger vehicles is at its peak. On-road studies—usually in areas chosen specifically to represent relatively benign environments—are well underway with vehicle manufacturers attempting to validate the reliability of their autonomous or semi-autonomous vehicles despite the physical challenges associated with safely integrating these vehicles on to the road, as well as the litigative, legislative and privacy issues with potentially serious implications resulting from their growing presence.

Concurrent to this, several private companies are field testing self-driving or driverless shuttles, buses and delivery trucks, integrating the autonomous mass-transit vehicles with the fleet of current vehicles, roads and infrastructure. At present, boundary conditions are placed on these mass-transit vehicles regarding what they are exposed to and what 'exceptional' conditions they must be programmed to overcome. This is done by restricting these vehicles to operate in geofenced locations (i.e. predefined routes within certain geographic boundaries) such as corporate campuses or as 'last mile travel' between transport hubs and final destinations. At present, this is regarded as a manageable challenge compared to 'open-world' driving. Despite this, there are still serious safety implications associated with using autonomous mass-transit vehicles and these implications are likely to significantly intensify as the vehicles become more autonomous, their routes become less restrictive and as road users become more complacent and less vigilant of driverless technology.

At present there are a number of well recognised automated shuttle and bus companies in operation. These include *Navya*, *EasyMile*, *SB Drive*, *Auro*, *Local Motors*, the Dutch autonomous vehicle manufacture, *2getthere* and the Belgian-Dutch company, *VDL Bus & Coach* (Be Automotive 2018; CB Insights 2017; Eijndhoven 2017). Autonomous mass-transit shuttles and buses have been operation since 2014. The following is a brief review of how these vehicles have operated in the past and how they intend to enter the open roads in the future.

NAVYA

In 2015, Navya launched a 15-person autonomous shuttle bus called the Arma and more recently, the AUTONOM which currently operates at several geofenced sites within France as well as international locations. According to the French manufacturer Navya, backed by vehicle manufacturers Valeo and Keolis, over 87 AUTONOM shuttles have been sold worldwide and the shuttles operate in Australia, Austria, Denmark, Germany, Japan, Singapore, Switzerland, USA and a number of other destinations (Navya 2017; Navya 2018). In Australia, Navya shuttles operate within Sydney Olympic Park (Sydney), Curtin University (Perth) and La Trobe University (Melbourne). To date, according to the vehicle manufacture, the shuttle has transported more than 275,000 passengers. No literature could be found regarding crashes or incidents involving these vehicles.

Named the RAC Intellibus®, two Navya shuttles also operate on a public road in Perth at present. The RAC Intellibus®, has travelled more than 15,918 km in autonomous mode and completed more than 4,548 thirty-minute rides. The shuttle travels along a pre-defined 3.5 km route (or a 30 minute ride) along the South Perth foreshore at speeds of up to 25 km/h. According to the RAC (Western Australia), the vehicle is exposed to 'increasing levels of interaction with different types of road users, traffic signs, traffic lights, right turn manoeuvres and traffic flows'. While the RAC Intellibus is based on the Navya Arma, the AUTONOM is capable of on-demand servicing and will be trailed in Perth, Paris and Las Vagas in the near future (Martin 2018).

The AUTONOM shuttle can operate roughly 9 hours on a charged battery and travel at up to 25 km/h with a battery capacity of 33 kWh. Weighing a gross 3,450kg, it can seat 11 passengers but accommodate another four standing passengers. The vehicle uses LIDAR sensors to provide 2D and 3D perception maps of the environment to allow for precise location of obstacles. It has a multitude of cameras, odometry sensors to measure the displacement and speed of wheel and a Global Navigation Satellite System (GNSS) antenna to communicate with the GPS sensor and the base station to know where the vehicle is relative to its destination. In terms of safety, the manufacturer specifies that the AUTONOM comes equipped with "4 handrails and 2 supporting bars, an emergency hammer, a safety pack, fire extinguisher and interior cameras". It also has 2 emergency stop buttons, SOS intercom, emergency breaks and parking breaks. No reference is made to the vehicles passive safety features. During 2017, Navya partnered with Las Vegas to launch a free pilot of the fully automated shuttle bus during the 2017 CES (a convention which serves to be the global stage for innovative designs).

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EASYMILE

Similar to the autonomous vehicle manufacture Navya, a joint venture between Ligier and Robosoft in France in 2014, saw the development and deployment of EasyMile and its EZ10 bus. The EZ10 travels along “virtual lines” and repeats the path continuously (Marshall 2017; Property Australia 2018). EasyMile is now being tested in San Ramon, California with no human operator present (since March 2018) and the EZ10 model has been deployed to 20 countries across Asia-Pacific, Middle-East, North America and Europe. Supervised by Easymile’s Fleet management software, the shuttle bus can carry up to 12 passengers (six seated and six standing) and claims to be operable on existing roadways with no additional infrastructure needed. The shuttle can also work on demand by passengers like the AUTONOM. The shuttle costs $250,000-$320,000 and can travel at speeds of up to 45 km/h, and when fully charged can run for 14 hours (Property Australia 2018). EasyMile EZ10 is currently being tested in small urban environments such as Bad Birnbach, Germany and in Sion (southwest Switzerland), 11 shuttle buses are in operation in normal traffic conditions. While the service initially commenced in a high-pedestrian traffic area in June 2016, on the 28 February 2018, the shuttles were introduced onto roads with other cars.

In a similar trial in Stockholm, Sweden, EasyMile partnered with various Swedish public transport providers to determine how the autonomous vehicles performs under real-world conditions for extended periods of time alongside cars, cyclists and pedestrians during an on-road trial. The buses communicate with sensor-enabled bus stops, traffic lights and road-signs through Ericsson's open API Connected Urban Transport platform (Marshall 2017). The EZ10 is also being trialled in Dublin, Ireland (Gorey 2018).

SOFTBANK

Softbank (Japan) has partnered with Advanced Smart Mobility and more recently with Yahoo! Japan to develop SB Drive - an autonomous passenger bus. It's intended that eventually the SD Drive bus will use Yahoo! Maps service and data. In February 2018, SoftBank partnered with Hino to trial a less shuttle-bus looking and more conventional bus-looking autonomous mass-transit service commenced in Tokyo. SoftBank's autonomous bus travels at 10km/h as part of a passenger-transportation service at Haneda Airport. In preparation for the 2020 Tokyo Olympics, SoftBank has partnered with Navya to introduce driverless technologies to shopping centres, airports and university campuses throughout Japan. It is anticipated that Japan will have driverless mass-transit shuttles and buses in full operation by the time of the 2020 Olympics.

OTHER AUTONOMOUS MASS-TRANSIT VEHICLE MANUFACTURERS

Further to the afore mentioned autonomous technologies, there are vehicle manufacturers and technology companies forming partnerships with transport agencies, telecommunication and infrastructure companies and governments to make autonomous mass-transit vehicles a popular transport mode. In China, four autonomous electric buses fitted with software and sensors from Haylion Technologies are being tested (Rogers 2018). The vehicles are larger than the typical 15-seater shuttle bus and have been running on a 1.2 km loop in the Futian district. It is anticipated that the vehicles will collect large amounts of real-world data for use. The Californian-based company Auro Robotics offers the autonomous service shuttles to campuses through a 'mobility as a service model'. The shuttles can be hired with clients paying insurance, maintenance and liability coverage for the vehicles.

Local Motors with the support of Airbus Ventures generated Olli - one of many advanced technology projects. Olli, like its many of its autonomous counterparts, move students around campuses or operate as a link between urban transit networks to transport passengers from one station to another. The actual vehicle bodies of Ollie are made using a 3D printing process developed by Local Motors. Further to this, IBM’s Watson cognitive learning platform is being applied using Olli. Liverpool, Sydney is expected to begin an autonomous shuttle or bus service to and from the planned Western Sydney Airport (to be opened in 2026). It is anticipated that the route will be 19 km in length and will use a dedicated rapid transit corridor lane with specialised road markings to accommodate the needs of the vehicles (Rogers 2018).

The literature demonstrates that autonomous shuttle buses are in operation globally and transitioning from operating in small, geofenced sites to larger and longer route-based paths. With this comes the inevitable interaction they must have with conventional vehicles and vulnerable road users. It is this interaction which is likely to give rise to safety concerns and which will need to be managed carefully by road and traffic authorities.

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3 AUTOMATED MASS-TRANSIT VEHICLES - VULNERABLE ROAD USERS

It is likely that issues related to how vulnerable road users will fair in the presence of autonomous vehicles will apply to autonomous mass-transit vehicles. As with fully autonomous passenger vehicles, the introduction of autonomous mass-transit vehicles raises the question of new communication needs since the active interactions which currently exist between drivers and pedestrians or cyclists such as gestures, eye contact, horns or flickering headlights will either no longer be present or function differently in autonomous vehicles? Using game theory, Millard-Ball (2018), analysed interactions between pedestrians and autonomous vehicles, focusing on their behaviour at crosswalks. The author concluded that because autonomous vehicles will be typically risk-averse, pedestrians are likely to behave with impunity and autonomous vehicles are likely to facilitate a shift towards pedestrian-oriented urban neighbourhoods, although this is likely to slow them down in urban traffic. Meeder et al. (2017) reviewed nine potential safety implications of autonomous vehicles towards pedestrians in general including: overall safety, human interaction, parking, accessibility, environmental impact, lane width and traffic speed. The authors attempted to determine if autonomy of vehicles was likely to adversely affect pedestrians and vulnerable road users. The authors concluded that it was difficult to predict the consequences of autonomous vehicles on pedestrian activity and pedestrian safety, particularly in urban environments.

At least at present, it is more than likely that autonomous mass-transit vehicles (unlike their passenger vehicle counterparts) will be specifically designed to operate on highly urbanised road networks and restricted zones where the presence of vulnerable road users are equal to, or if not greater than the presence of other vehicles. The travel speeds of the autonomous vehicles should therefore be low to be able to account for abrupt manoeuvres by vulnerable road users until all road users are educated about intelligent road use, particularly around autonomous vehicles. It is more than likely that automated mass-transit vehicles will pose less danger to vulnerable road users than fully autonomous passenger vehicles driven at speed, and their potential benefits should be viewed favourably according to literature. In January 2018, Stockholm, Sweden, telecommunications giant Ericsson commenced an experiment using autonomous public transport. Their two autonomous shuttle buses drove at up to 24 km/h within pedestrian areas and along bike lanes and roads (Schaft 2018). While to date there have been no reports of fatalities involving vulnerable road users and autonomous mass-transit vehicles, scientific reports from this experiment have yet to be published.

A study by Combs et al., (2018) noted that sensors used by autonomous vehicles can detect pedestrians in advance of fatal collisions from in 30-90% of fatalities. While the authors noted that combining sensor technologies is likely to offer the greatest potential for eliminating fatalities, they concluded that it may be unrealistically expensive. However, in the realm of mass-transit autonomy, where large companies are liable for the lives of multiple passengers at a time, this may be a necessary investment in ensuring vulnerable road user safety and realising fatality reductions. While mass-transit vehicles which primarily operate on high-speed freeways may not be equipped with these sensors (provided that they are capable of boarding and alighting passengers with minimal risk to vulnerable road users), shuttles and buses in selected urban areas, non-freeway streets and rural towns may benefit from these sensors to help protect pedestrians. Combs et al., concluded that while technologies are being developed for automated vehicles to successfully detect pedestrians in advance of most fatal collisions, it is unlikely that automated vehicles will radically reduce pedestrian fatalities in the short term.

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4 AUTOMATED MASS-TRANSIT VEHICLES INTERACTING WITH CONVENTIONAL VEHICLES

The most significant concern related to the safety of autonomous mass-transit vehicles in the presence of non-autonomous or partially autonomous vehicles is that the human drivers in the latter two vehicle types are likely to make errors which autonomous vehicles cannot anticipate and therefore, react to. One means of quantifying or assessing the frequency of adverse reactions between autonomous vehicles (and hence autonomous mass-transit vehicles) and convention vehicles, is to look at real-world data involving these vehicle types. However, given how novel fully autonomous technology is at present, there are only a limited number of studies that have investigated the frequency of crashes involving fully autonomous vehicles.

A preliminary analysis of the cumulative on-road safety record of self-driving vehicles for three companies approved for autonomous vehicle testing in California (Google, Delphi, and Audi) was conducted by Schoettle and colleagues (2015). The study of autonomous vehicles from 2012 to 2015 counted 11 crashes involving self-driving vehicles on public roads. The autonomous vehicles were found not to have been at fault in any of these 11 occurring in autonomous mode. Although the frequency of crashes was found to increase in the final year of the study (potentially corresponding to the increase in the number of self-driving vehicles), the vehicles when operating in full autonomous mode were not responsible for any of the crashes. The authors noted two important caveats; the first being the distance accumulated by self-driving vehicles was relatively low in the experiment (approximately 1.2 million miles compared to 3 trillion annual miles driven in the US by conventional vehicles), and that self-driving vehicles were only driven in a limited, (usually less demanding) conditions compared to conventional vehicles. The authors noted that ultimately, the exposure of autonomous vehicles was not representative of the exposure for conventional vehicles and care should be taken predicting future crash-related trends of autonomous vehicles in general.

More recently, in an effort to promote safety and accountability, the California Department of Motor Vehicles (CA DMV), mandated three specifics related to autonomous vehicles. The CA DMV required that:

1. Trained human drivers remain behind the wheel at all times during testing of autonomous vehicles (regardless of the level of autonomy). In order to accommodate/adhere to this mandate, vehicle manufacturers of autonomous vehicles were/are required to retrofit a steering wheel and control pedals for the human driver in their fully automated vehicles
2. Two types of reports be drafted and made available to the public following failure of any autonomous technology during testing. These reports include:
   a. A concise list of all occurrences of autonomous technology disengagements
   b. A detailed summary of events for those occurrences with results in a collision and/or property damage or injuries

Using the above reports (a) and (b), Favarò et al. (2017), analysed the crash types which autonomous vehicles were involved in. They concluded that there were 26 crash events between September 2014 and March 2017 involving vehicles manufactured by Google, General Motors, Cruise Automation, Delphi and Nissan despite over 30 permits being issues to various autonomous vehicle manufacturers for testing of their vehicles on Californian roads. Similar to the study by Schoettle and Sivak (2015), Favarò et al. (2017) noted that of the 26 autonomous vehicle crashes, in 22 instances the autonomous vehicle was deemed to be not-at-fault. Of the four instances where the autonomous vehicle was at fault, two occurred when the vehicle was in manual mode. The majority of collisions (18 out of the 26) were rear-end.

Although there are currently limited data to draw definitive conclusions about autonomous vehicles, and in particular autonomous mass-transit vehicles, trends suggest that dangers to vehicle occupants or passengers exist as a result of drivers of conventional vehicles failing to anticipate the programmed behaviour of autonomous vehicles. It is likely that in the case of mass-transit buses or shuttles, that drivers will assume that the vehicles will always travel at a conservative passenger-friendly or vulnerable road-user friendly speed, and will either constantly attempt to overtake these vehicles or, as shown in the statistics analysed by Schoettle and Sivak (2015) and Favarò et al. (2017), rear-end these vehicles – two potential crash configurations driverless technology cannot actively avoid.

The safety issues related to autonomous mass-transit vehicles therefore, are apparently largely related to drivers of conventional vehicles failing to recognise the programmed behaviour of the driverless technology. It is often assumed, particularly by risk-taking drivers, that their risk-averse counterparts will be forgiving, or at least tolerant of erratic driving behaviour and will adjust their behaviour to avoid a collisions or incidents on the roads. Autonomous mass-transit vehicles are limited in their ability to actively avoid erratic behaviour and, although the vehicles are programmed to detect and adjust their speed and direction due to detected hazards, are unlikely to be able to react to perceived hazards as a human driver would. This should be considered when setting safety standards with which autonomous mass-transit vehicles have to comply.

5 PASSIVE SAFETY IN AUTONOMOUS MASS-TRANSIT VEHICLES AND OCCUPANT INJURY PROTECTION

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The standard Navya Arma / AUTONOM vehicles, like most other autonomous shuttles manufactured by other driverless-technology companies come fitted with handholds (x4), supporting bars (x2), an emergency hammer (x1), a safety pack (triangle, safety vest and first aid kit), fire extinguisher and interior cameras. In addition this, the vehicles are usually also fitted with 2 emergency stop buttons, an SOS intercom, emergency and parking brakes.

Advanced passive safety features however, are lacking in these vehicles and is of significant concern since these autonomous mass-transit vehicles are unlikely to be able to take evasive action in emergency situations to avoid crashes due to poor driver behaviour. Lap belts as an example, can be purchased as an extra, but since the shuttles only accommodate for 11 seated passengers and 4 standing passengers, those standing may be exposed to greater danger in the event of an impact. The vehicles are not fitted with active headrests despite these vehicles being exposed to a high number of rear-impacts according to current trends (Favarò et al. 2017). Further, the vehicles are not fitted with side curtain airbags or other energy absorption technology which may actively reduce the likelihood of serious injuries in the event of a high impact crash i.e. side impact configuration, or rollover. While the vehicle centre of gravity is relatively low to the ground and rollovers are an unlikely event, the occurrence of side impacts and rear-impacts are more realistic and passenger safety in this impact configuration should be considered.

The seating configuration within these shuttles is also of concern. Passengers are not restricted to sit in a forward-facing fashion as they do with the conventional buses and shuttles, which means that during an impact, depending on vehicle impact direction, passengers may be exposed to passenger-passenger contact. In the event that the passengers are unbelted, this could pose a serious injury threat. Passenger seating direction and seating preferences are currently being investigated by MUARC in a recently commenced study.

6 SAFE SYSTEM THINKING APPLIED TO AUTONOMOUS VEHICLES

It is critical that an overarching philosophy regarding vehicle and occupant safety pertaining to autonomous mass-transit vehicles be developed so that manufacturers of these vehicles can be both held to minimum standards of active and passive safety, as well as creating incentives for achieving the best possible occupant and vulnerable road user protection. At present no such philosophy could be found in the literature. Until a road safety philosophy applicable to autonomous vehicles and autonomous-mass transit vehicles is developed, it is recommended that Safe System thinking be extended to these vehicle types. The five pillars of Safe System are listed below, and where applicable, how the pillars could apply to mass-transit autonomous vehicles have been noted.

ROAD SAFETY MANAGEMENT

At present, an internationally represented regulatory body to oversee the performance of autonomous mass-transit vehicle and their effect on the current transport system is lacking. In addition to this, the autonomous mass-transit industry would benefit from

- Dedicated committees to set regulations specifying minimum performance requirements of autonomous (mass-transit) vehicles and,
- Dedicated committees to oversee regulatory testing of autonomous mass-transit vehicles, assess their performance and ensure they conform to standards before they are released on public roads.

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INFRASTRUCTURE

Until the majority of (passenger and mass-transit) vehicles on the road network are autonomous, it is recommended that the following be present ensure that road-safety of autonomous mass-transit vehicles are in line with Safe System principles:

- Dedicated autonomous vehicle transit lanes (currently known as Rapid Transit Lanes, RTL) may need to be developed to separate autonomous vehicles from fast-travelling conventional vehicles. RTL are typically characterised by unique and defined lined markings, advanced sensor-based traffic signals and speed signs
- Physical barriers or infrastructure to separate the lanes in which autonomous vehicles travel from conventional vehicles to prevent interaction between the two vehicle types
- All road signs (advisory speed signs, warning signs, informational signs, mandatory instructions, priority signs, routing indication signs, police instruction and prohibition or regular signs) will need to conform to a standard that both the sensors on autonomous vehicles, as well as human drivers, can identify easily and interpret correctly. Signs should be visible at all times, in all weather conditions.

SAFE VEHICLES

Independent of the presence of conventional vehicles, passive and active safety of autonomous vehicles, and in particular, autonomous mass-transit vehicles should at least be brought into line with those requirements applicable to human-driven mass transit vehicles. At present, the inclusions of in-vehicle safety features such as pretensioning seatbelts, active head rests, airbags, or the inclusion of protective material on the vehicle body to absorb impact forces which a crumple zone would otherwise provide, are lacking and exposes the passengers to dangerous forces, even if the mass-transit vehicles do only travel at speeds under 50 km/h.

Literature regarding active safety features built into these autonomous vehicles could not be found. However, features such as forward collision warning systems, electronic stability control, anti-lock braking systems, traction control, electronic brake-force distribution and brake assist should all be incorporated into the hardware and software of autonomous mass-transit vehicles.

ROAD USER BEHAVIOUR

Education schemes may be necessary for passengers and vulnerable road users, centred on the capabilities of the autonomous systems and their limitations, including the possibility of system failures.

Extra training or education should be provided to pedestrians regarding making intelligent road-safety decisions and being wary of autonomous vehicles that make judgements using different criteria to those adopted by conventional drivers. Eye contact and facial expressions of drivers, which are usually relied upon by pedestrians before road crossing is initiated, would no longer exist and pedestrians may need to make conservative decisions regarding their crossing decisions.

POST-CRASH RESPONSE

Post-crash response should be immediate and be activated via an automatic collision notification system built into the autonomous mass-transit vehicle in order minimise treatment response times. At present, automatic collision notification systems are present in various vehicle makes and models, but these are only activated during a vehicle-vehicle collision. With autonomous mass-transit vehicles, similar behaviour might be required in the event of a pedestrian impact with little or no reliance on passengers on-board the autonomous mass-transit vehicles.

Further to this, camera's on-board cameras may be accessible by emergency personnel to determine the state of the vehicle and passengers following a crash.

It is likely that automatic collision notification technology is currently available in autonomous mass-transit shuttles given the supervision of the shuttles currently done by the manufacturers and the knowledge of the vehicle whereabouts at any specific time from vehicle GPS signals.

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OCCUPANT INJURY PROTECTION

As previously mentioned, the area of occupant injury protection related to autonomous mass-transit vehicles requires a significant amount of research. At present, the smaller autonomous mass-transit shuttles can ferry up to 15 passengers at a time. A crash involving a shuttle bus therefore, could involve up to 15 individuals and achieving zero injury and death may require the presence of advanced occupant protection technology which is currently not present.

7 CONCLUSIONS

Current literature demonstrates that autonomous mass-transit vehicles are now in operation in various geofenced locations across the globe. They are also slowly making their way onto the open road network, with this transition likely to become more rapid in the near future.

At present other than within trial sites, there is no dedicated road infrastructure to accommodate these vehicles on the open-road in most of the countries where the autonomous mass-transit vehicles are being implemented. This is likely to present dangers not only to the passengers who ride these vehicles, but also to vulnerable road users as well as the drivers and passengers of conventional vehicles. Furthermore, autonomous mass-transit vehicles are being introduced with little education to the public regarding how they operate or their potential dangers. Vulnerable road users are likely to be most at risk, given how novel the vehicles are and the manner in which these machines interact with objects and road users around them.

The passengers of the autonomous vehicles themselves are exposed to significant risks due to the absence of passive safety features. Although the vehicles are only capable of travelling at relatively low speeds, there are still dangers to passengers and vulnerable road users given that the autonomous mass-transit vehicles travel amongst conventional vehicles which travel at relatively high speeds and have the potential to be driven erratically. Strategies should be developed regarding how to integrate autonomous vehicles safety onto the current network, how best to separate and/or to protect them from fast-travelling conventional vehicles and vulnerable road users, how to test them against stringent safety standards and how to educate the public regarding their benefits and the potential dangers associated with the vehicles. Overall, it may be necessary to form dedicated agencies to develop, control and monitor the passive and active safety features within autonomous mass transit vehicles, especially given that conventional vehicles are subject to a full range of safety standards and consumer expectations.

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