TRAFFIC ENGINEERING IN THE AGE OF AUTONOMOUS VEHICLES

Author

GRAHAM MCCABE

Qualifications

BE (CIVIL HONS), UNIVERSITY OF WOLLONGONG 1996

MASTER OF TRANSPORT AND TRAFFIC, MONASH UNIVERSITY 2003

MASTER OF BUSINESS ADMINISTRATION, LATROBE UNIVERSITY /CHIFLEY BUSINESS SCHOOL, 2011

Associations

MEMBER AUSTRALIAN INSTITUTE OF TRAFFIC PLANNING AND MANAGEMENT

MEMBER, ROADS AUSTRALIA NETWORK RELIABILITY REFERENCE GROUP

Role

SERVICE LEADER, TRANSPORT OPTIMISATION AND PLANNING – GHD PTY LTD

GRAHAM.MCCABE@GHD.COM

Presenter

GRAHAM MCCABE

ABSTRACT

Currently road networks are designed and constructed based on current the current vehicle fleet projected into the future. The development of smart, connected vehicles and automated vehicles will have a significant impact on the width of roads, amount of parking required and how we travel around.

This paper considers the impact of increased automation on the way we plan and design road networks and alternate uses of existing traffic lanes and parking to create a more sustainable transport system and how we can reclaim our built environments for walking and cycling.

INTRODUCTION

The challenges presented by autonomous vehicles mean that planners, developers, roads authorities and the community need to think about autonomous vehicles and how they will fundamentally change society. This is new age is is coming sooner than most practitioners think. The pace of development of self-driving and autonomous is accelerating. As at the end of mid November 2015 (January 2016)[1], Google, Daimler, Uber and Tesla have fully autonomous vehicles operating on the streets of California, Nevada and Texas. The project lead for the Google Car project has publicly stated that he expects his 14 year old son to never need to learn to drive and to use google cars.

Before we can even consider how we integrate the technology of autonomous vehicles into our transport system, professionals must understand how future cities to be created – not just in technology but planning and design. This paper outlines the current status of the development of self-driving and autonomous vehicles and how they will affect the transport system and urban environments over the next decade.

SELF-DRIVING VS AUTONOMOUS VEHICLES

Self-driving vehicles (for example the Tesla Model S) and autonomous vehicles (the Google pod car) are not the same thing. A self-driving vehicle has the same attributes as a modern car, truck or train but has the ability to drive itself within the environmental parameters set for it and has the ability for a driver to steer it; set its direction and speed . In contrast, an autonomous vehicle has the ability to fully operate independently of any human interaction (including goal setting).

The automotive and software industries are each travelling the similar but separate paths in this area, with the automotive industry (such as Daimler and General Motors) currently focusing on self- driving and the software industry (such as Google and Apple) focusing on autonomous driving with no input from the vehicle operator (in terms of safety systems). There are some companies who are working in the cross-over space between the two such as Tesla and Volvo.

Self-driving Vehicles

Self-driving Vehicles are currently more advanced than Autonomous vehicles, with the many brands featuring self parking features. Others such as the Mercedes C class include features such as stay in lane, dynamic gap and adaptive cruise control. However, the most advanced self-driving cars are produced by Tesla.

The Tesla Model S (Figure 1) is a modern, fully electric car with a range of approximately 900 km that can contains an autopilot feature that includes adaptive cruise control, lane keeping with automatic steering (and automatic lane change via minimal interaction) and self parking. Notably, this car has the ability to update itself via wi-fi and in October 2015, a software download enabled full self-driving overnight with no interaction with law enforcement or regulators. Other manufacturers such as Daimler and General Motors are following suit and either have partial self-driving modes or are soon to release them.

Autonomous vehicles

In comparison to the Daimler and General Motors, Google and Apple are focusing on fully autonomous vehicles, with the goal to be the operating system provider. Google cars, including the pod car (Figure 2) have completed more than 1.6 million kilometres and are licenced to operate in California, Nevada and Texas. The car is fully autonomous but is currently speed limited to 40 km/h (35 mi /h). It has no steering wheel, accelerator or brake and operates independently of the

---

[1] This will be updated prior to submission of the final paper.

occupant.

Google has identified that its prime concern and focus for having fully autonomous vehicles is the "hand off problem" where the "driver" is required to change from doing other things (e.g. watching Youtube or sleeping) to actively driving the vehicle. Ensuring that this is smooth is key to the success of self-driving cars.[2]

While Tesla and Google are the most prominent proponents of the two development streams of vehicles, others are working in this space, and the advances in other areas of transport, logistics and mining will flow through to personal and public transportation.

Figure 1 Tesla Model S (Tesla, 2015)[3]

Figure 2 The Google Car (Google, 2015)[4]

[2] Google Car Project monthly report October 2015, https://www.google.com/selfdrivingcar/files/reports/report-1015.pdf viewed 28 November 2015
[3] Telsa Model S https://my.teslamotors.com/en_AU/models/design viewed 27 November 2015
[4] Google Car, https://www.google.com/selfdrivingcar/, viewed 27 November 2015

ADVANCES IN SELF-DRIVING AND AUTONOMOUS TRANSPORT

While many transport planners, traffic engineers and urban planners consider an autonomous traffic network to be 20 – 30 years away, a number of the key aspects of autonomy exist in the current mining and transport and logistics applications. These features are either directly applicable to self-driving and autonomous vehicles; or are easily transferrable.

Mining applications

Large miners such as BHP Billiton and Rio Tinto already use automated haulage trucks. These vehicles operate with only maintenance and refuelling breaks and interact with human controlled vehicles. They are guided by GPS plotted maps and have range finding LIDAR mounted on the cab to detect the environment and the position of the surrounding vehicles and their location when the GPS signal is blocked. These trucks have been recorded as improving efficiency by 12 percent.

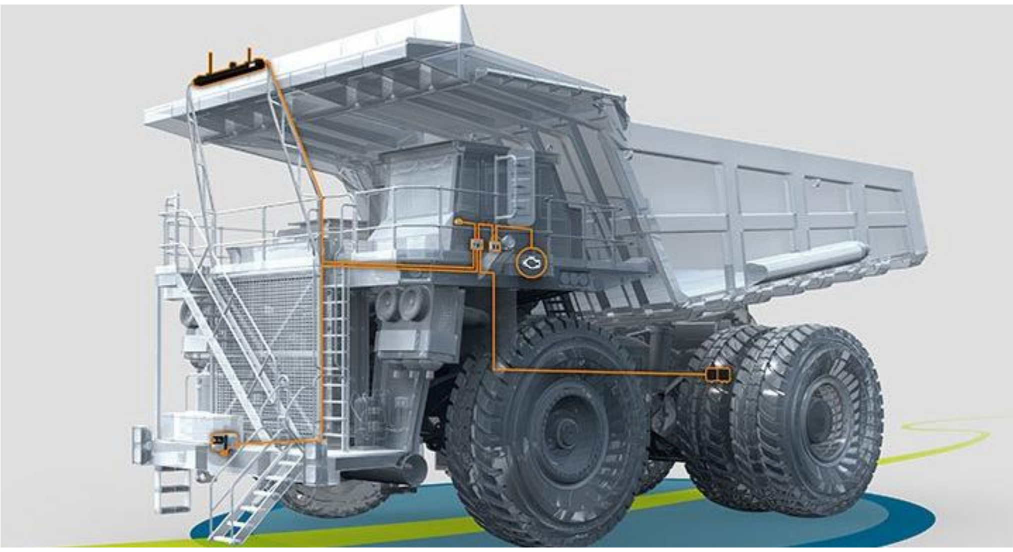

Figure 3 Rio Tinto autonomous truck (Asi Robots)[5]

Transport and logistics applications

Many modern warehouses operate with robots operating on guideways collecting materials and manufactured goods and distributing them around the warehouse with minimal human interaction. Many of these robots have sensors to detect the position and speed of the other robots and if there are humans operating within their environment.

Driverless passenger trains have operated on metro rail systems since 1968 when the Victoria Line, part of the London Underground built with driverless operations. While these trains still have “drivers” controlling when the doors open and close and the train starts (but not stops), many modern metros are fully driverless, with the vehicles being managed from central control rooms. The levels of automation have progressively increased to the point where Rio Tinto will be running 2 km long iron ore trains in the Pilbara region of north west Western Australia remotely from Perth, 1000 km away. While automated trains run on fixed guideways and closed systems, automated freight trains interact with railway level crossings, nature and wildlife requiring a high level of remote sensing using and this is directly applicable to the road system.

---

[5] Rio Tinto autonomous truck, http://www.asirobots.com/autonomous-fleet-outperforms-manned-fleet-by-12/ viewed 29 October 2015

In the maritime freight industry, the loading and unloading of ships and movement of containers within port environments is already managed remotely from a control room, with fully automated cradles moving containers between trains, trucks and ships. These cradles are fitted with sensors and electronic motors.

Figure 4 AutoStrad cradles at Port Botany in Sydney (Sydney Morning Herald, 2015)[6]

Daimler and Volvo are already trialling self-driving trucks and semi-trailers where the driver is not responsible for highway driving. This evolution in trucking will enable companies to effectively manage driver fatigue and enable drivers to be alert and aware in city traffic. This change is only the first step to eliminating the truck driver and truck crashes completely.

Figure 5 Future Freightliner self-driving vehicle.[7]

Personal applications

While these technologies are new to the public, their application within controlled private environments will inevitably translate to the public space and change our transport system. The Telsa and Google car options are currently out of the price range of most car owners and private users. However, there are now companies such as Cruise are promising self-driving kits (initially

---

[6] Sydney Morning Herald, http://www.smh.com.au/nsw/sydneys-patrick-terminal-goes-automated-with-fewer-staff-but-dancing-robots-20150617-ghqc24.html, viewed 15 August 2015

[7] https://www.youtube.com/watch?v=auPyP2qfudk viewed 28 September 2015

for Audi) at a price tag of $10,000[8], bringing self-driving and ultimately autonomous driving into the market faster than previously thought possible.

TRANSPORT SYSTEM CHANGE

The application of self-driving vehicles and autonomous vehicles will result in a fundament challenge to the transport system. Even the Google car currently requires a nominal driver. But if the vehicle is safer than a human - should we require a “driver” at all? California and Nevada (the only jurisdictions in the world that allow fully autonomous vehicles) still do not have a legislative framework relating to the vehicles. The law in California has been under development since early 2014.[9] There are also differences within the vehicle and software developers about the insurance responsibility for self-driving and autonomous vehicles. Google and Tesla for example have taken insurance responsibility for the operation of their cars under self-driving and autonomous mode.

Three key questions within the transport system once these issues are solved relate to the notion of car ownership, the role of ride sharing and the future of public transport.

Car ownership

Car ownership is currently based on need to have access to a vehicle across the day (though primarily during the morning an evening peak commuting periods. Once we no longer drive ourselves, we will no longer need to leave our cars at our workplace, train station, school or shopping centre while we undertake our activities. The car take itself home; can go off to a storage site or be made available to other users (as is the case with car share schemes). In many western countries, car ownership is high in suburban areas. However, if an autonomous car can drop a commuter off at the train station and return home to take children to school; and then do a shopping trip, will car ownership decline?

With the ability to pre-book a car to pick us up or dial one on the spot will we even need to own a car? Daimler is already working in this area, as is Uber and it is easy to envisage Hertz, Zipcar and others similarly joining this race. Without a human at the wheel, taxi fares can be expected to drop significantly to be competitive with public transport fares.

The converse to the reduced car ownership is the increased number of vehicles circulating on the road networks - returning to home, making additional trips or going to a storage location. Road management strategies are currently focused on supporting the peak commuting trips, but once these vehicles are continuing to operate on road networks, the demand for parking restrictions such as Clearways and No Stopping in the counter peak direction may increase.

Ride sharing

Car occupancy in the western world is low and varies from 1.2 in Australia[10] to around 1.5 in Europe[11]. This equates to 12 - 15 people for every 10 cars. A small shift equivalent to a school holiday period (10 percent reduction in the number of cars) can result in a significant decrease in overall congestion. The risk to the regulatory system is similar to the challenge created by taxi proxies like Uber. The market dynamics of autonomous vehicles will change the transport system in ways still to be determined. In many South American, South Asian and African countries, minibuses and tuk-tuks operate as a pseudo public transport system, collecting people and carrying them to a destination on a negotiated cost basis.

---

[8] http://reserve.getcruise.com/join-the-driverless-revolution viewed 27 November 2015
[9] https://www.dmv.ca.gov/portal/dmv/detail/vr/autonomous/auto, viewed 27 November 2015
[10] http://chartingtransport.com/tag/car-occupancy/ viewed 25 November 2015
[11] http://www.eea.europa.eu/data-and-maps/indicators/occupancy-rates-of-passenger-vehicles/occupancy-rates-of-passenger-vehicles-1 viewed 25 November 2015

Fleets of autonomous mini-vans trawling the streets, looking for riders may become part of the future. It is already possible to get a discounted ride using *UberPOOL* by sharing the costs of the trip. With autonomous vehicles floating around the road network, increasing congestion, the opportunities for lower cost fares for travel make become cost competitive with public transport (though the personal interaction issues may be a challenge in a small vehicle as discussed in Gizmodo)[12].

Public transport fleets

At the Australian Bus Industry Confederation (BIC) Conference, Singapore 2015, autonomous bus development[13] was highlighted by Michael McGee, the CEO of Transit Australia Group (owners of Bustech, a bus vehicle manufacturer). Autonomous buses will result in a change in the role of bus drivers to be more like a customer service agent – opening and closing doors and providing tourist information. Singapore is about to trial a fully autonomous bus on one of its routes and bus operators may opt to sit in the demand responsive transit space rather than fixed routes with large vehicles.

The CitiMobil2 project in France operated autonomous buses along a 1.3 km stretch of pedestrian plaza, with the buses limited to 12 km/h. While these systems are currently small scale, there is no limit to their ability to operate at the same speeds as normal city buses in traffic environments.

Figure 6 CitiMobil 2[14]

VEHICLE SAFETY

Self-driving and autonomous vehicles are inherently safer than human drivers. Due to the operating rules, these vehicles follow the local road rules and speed limits to the letter and these vehicles will currently only operate at a speed at which they can stop safely based on the input sensors.

Rule adherence

Utopians working in the autonomous vehicle field have predicted that these vehicles will eliminate road fatalities. While these vehicles do not drink drive, get fatigued or disobey road rules, they will still be interacting with humans who may drink walk, cross the road at the wrong time or disobey road rules. So while crashes and fatalities will reduce, they will still occur. The Google Car project

---

12 http://www.gizmodo.com.au/2015/06/i-used-uberpool-and-im-still-not-sure-if-it-should-be-in-australia/ viewed 27 November 2015
13 http://bic.asn.au/information-for-moving-people/bic-national-annual-conference viewed 20 September 2015
14 http://www.citymobil2.eu/en/ visited 20 November 2015

has (at November 2015) had 29 crashes[15] – none of which was caused by the vehicle. All were either by other drivers disobeying street signs or when in the control of their human co-pilot.

Safe stopping

The development of sensing vehicles using a combination of LIDAR, radar, cameras and ultrasound enables vehicles to see around them for up to 250 metres (Figure 7). As shown in

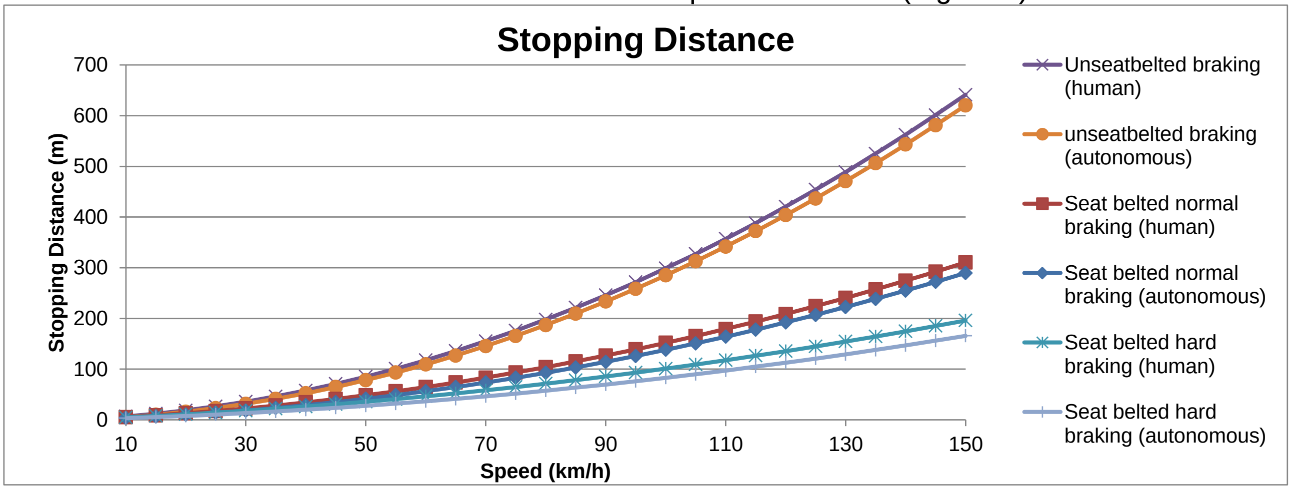

Figure 8, in normal conditions, this enables a vehicle to travel at up to 140 km/h without human interaction (braking at 3.5 m/s^2); With emergency braking (7 m/s2), this speed can increase to over 160 km/h.

The draw-back of this type of technology is that the sensors can only see within their range and trees, buildings and curves block the vehicles driving unit from understanding what is ahead. Under this circumstance, the vehicle would slow down until it can safely stop within the sensor range.

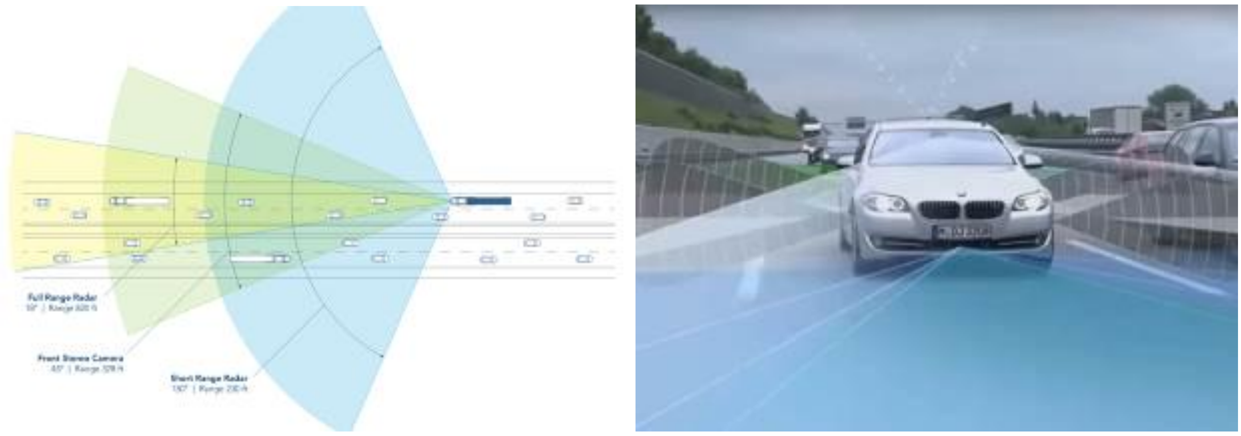

Figure 7 Freightliner vehicle perception[16] (left) and Self-driving car sensors (right)[17]

[15] Ibid (Footnote 4)
[16] http://www.williamhertling.com/2015/05/freightliner-introduces-licensed-autonomous-truck/ viewed 27 November 2015
[17] https://www.youtube.com/watch?v=xHV3dXRCM7A viewed

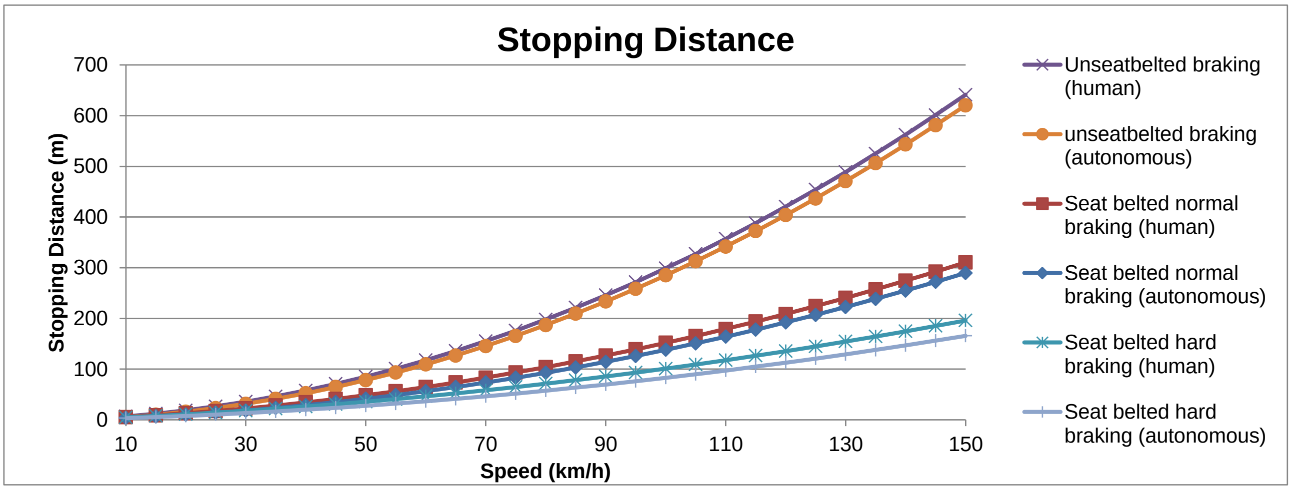

Figure 8 Stopping distance at various speeds

Vehicle connectivity

Vehicle interconnectivty using Cooperative Intelligent Transport Systems (C-ITS), Vehicle to Vehicle and Vehicle to Infrastructure communications, this distance can become as far as vehicles can communicate with each other. Inbuilt high quality and up-to-date 3D maps such as those developed by *HereMaps* and Google StreetView will provide route guidance.

Figure 10 shows how well placed sensing infrastructure can combine with vehicle sensing to cover a winding road in an urban environment to ensure that self-driving and autonomous vehicles are not limited by existing roads.

Figure 10 shows how this translates into what the first car on the left of screen can "see" through a combination of sensors – far more than a human can, enabling higher speed operation within safety parameters.

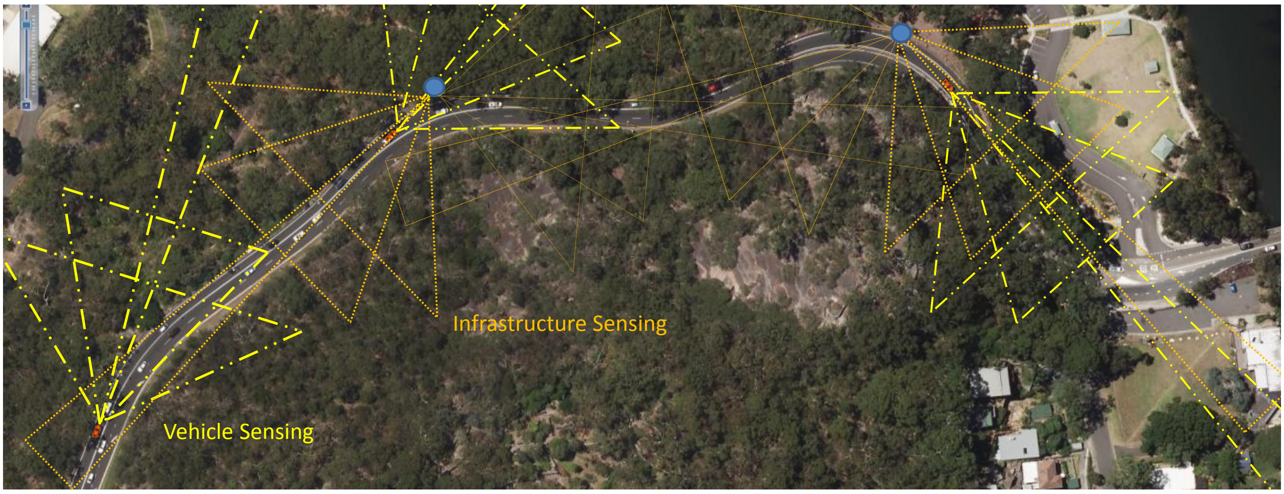

Figure 9 Combined vehicle and infrastructure sensing (SIX Maps modified by GHD)[18]

[18] https:/maps.six.nsw.gov.au/ viewed 27 November 2015

Figure 10 Vehicle awareness (SIX Maps modified by GHD)[19]

VEHICLE AND ROAD DESIGN

With the development of direct drive motors and flat battery packs (as currently is displayed in the Tesla Model S), the current body shapes for vehicles will become redundant. The future Freightliner shown in Figure 5 is an interim step. With autonomy, direct drive motors and batteries as part of the trailers, the drivers cab and sleeping area will no longer be required. With the cab having up to 25 per of the turbulence and friction and 7 tonnes of mass, having a more streamlined and shorter vehicle can improve operations and capacity and freight productivity. A conceptual layout for a revised B-Double configuration is shown in Figure 11.

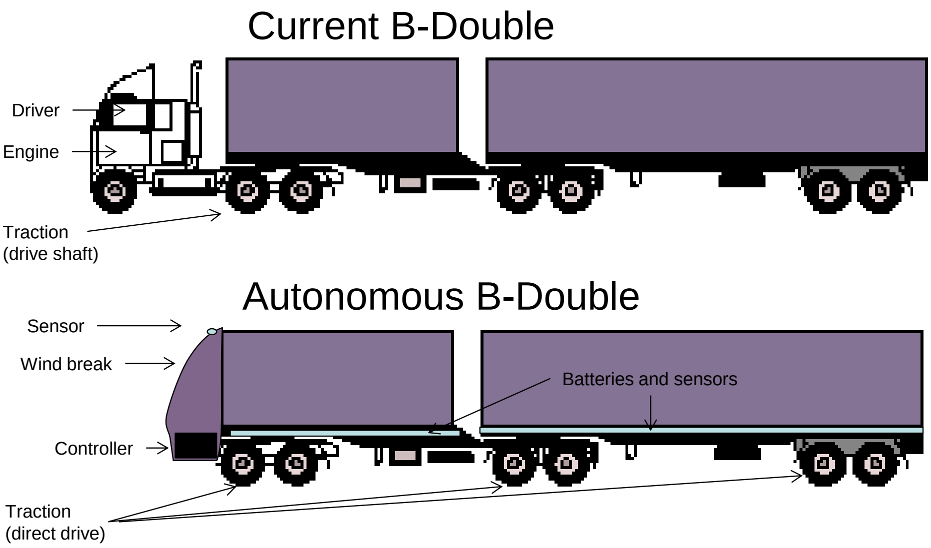

Figure 11 Autonomous freight (Austroads modified by GHD)

Cars and buses may also have different designs based on their function or whether it is short or long distance travel. Cars operating over long distances at high speeds may have a more aerodynamic shape than existing vehicles, while short distance electric buses and taxis may look like pods on

[19] https:/maps.six.nsw.gov.au/ viewed 27 November 2015

wheels. 

Figure 12 shows some variants of future vehicle types.

Figure 12 Future vehicles –pod[20] and taxi[21] (from left to right)

As the future vehicle types take over the road network, designing roads to cater to human perceptions, fatigue and reaction time will be increasingly less important. Roads can be designed to accommodate the optimal requirements of the vehicles operating on them. A truck with 12 direct 240 kw motors (currently on the Tesla Model S) will not suffer the gradient effects as a 600 kw diesel engine on a prime mover). This will enable new motorways to be straighter, including going over hills than previous and motorway design will become more about protection of the environment and community than engineering to allow vehicles to operate. Figure 13 shows the

[20] http://www.goauto.com.au/mellor/mellor.nsf/story2/68647CF75802D2ABCA257877002D2E03 viewed 27 November 2015
[21] https://drivingtothefuture.wordpress.com/tag/prague-taxi viewed 25 September 2015

evolution of road design from access roads to freeways and future freeways.

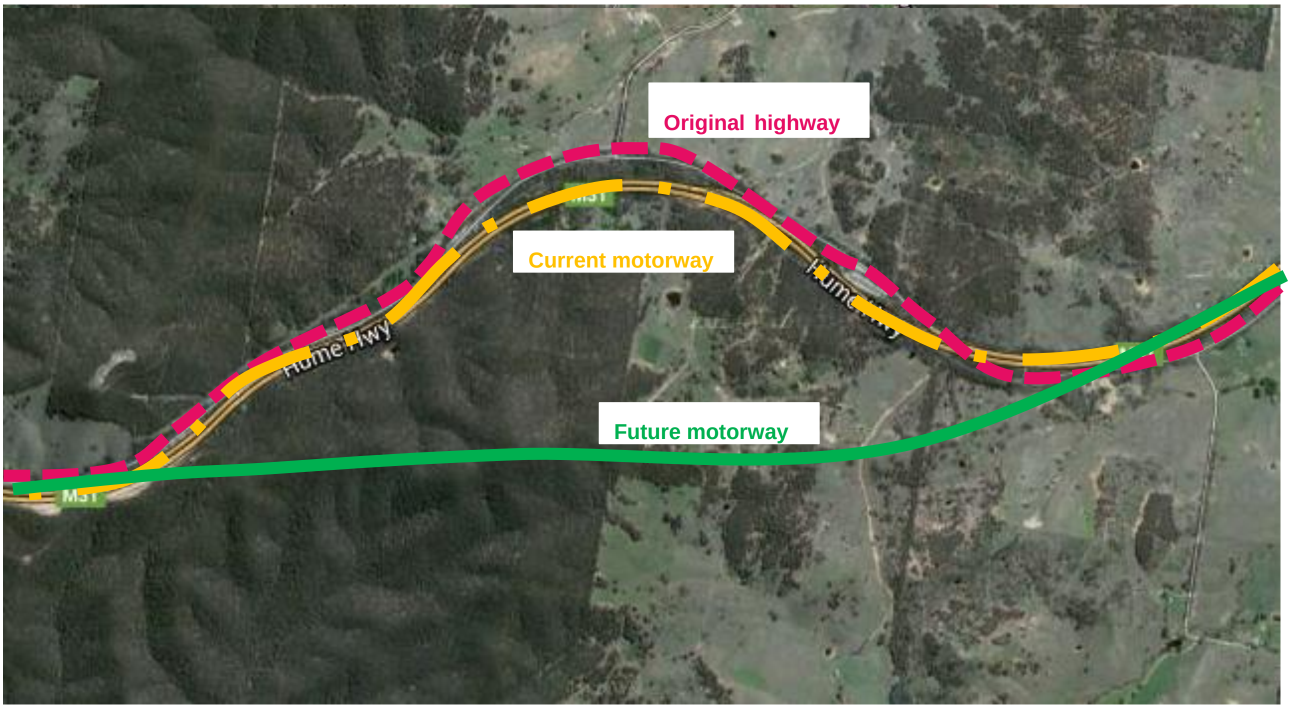

Figure 13 Road design evolution (Six maps modified by GHD).

INCREASING ROAD CAPACITY

Self-driving and autonomous vehicles will also result in significant increases in road capacity. Human reaction time is currently a limiting factor in driving on road network capacity and reliability.

As drivers reduce the relative gap to the vehicle in front, the probability of an incident occurring increases. Additionally driver distractions such as phone usage, fatigue and general inattention increase reaction time, driving down capacity and causing shockwaves in congested environments.

A microsimulation test network (Figure 14) using the Paramics program was evaluated to determine the capacity improvements that result from removing the human factors in merging by removing the reaction time factor. Figure 15 shows that for each number of lanes on the freeway, a change to self-driving or autonomous merging increases both speed and capacity within the system.

Figure 14 Test microsimulation network

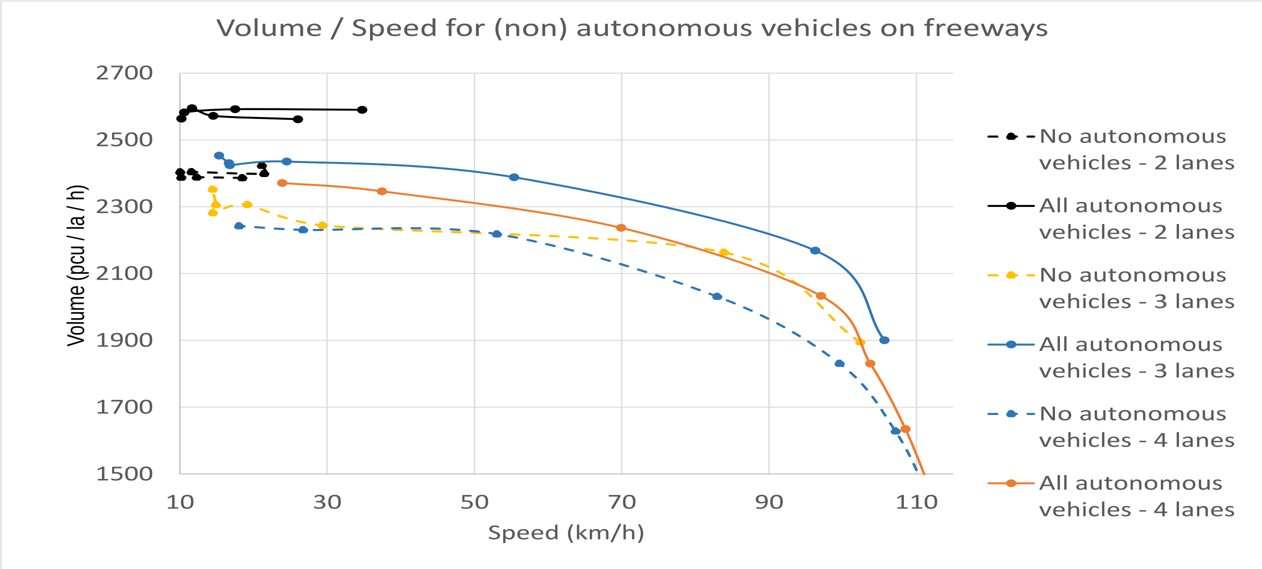

Figure 15 Freeway capacity for a ramp merge (2 to 4 lanes, with(out) autonomous vehicles)

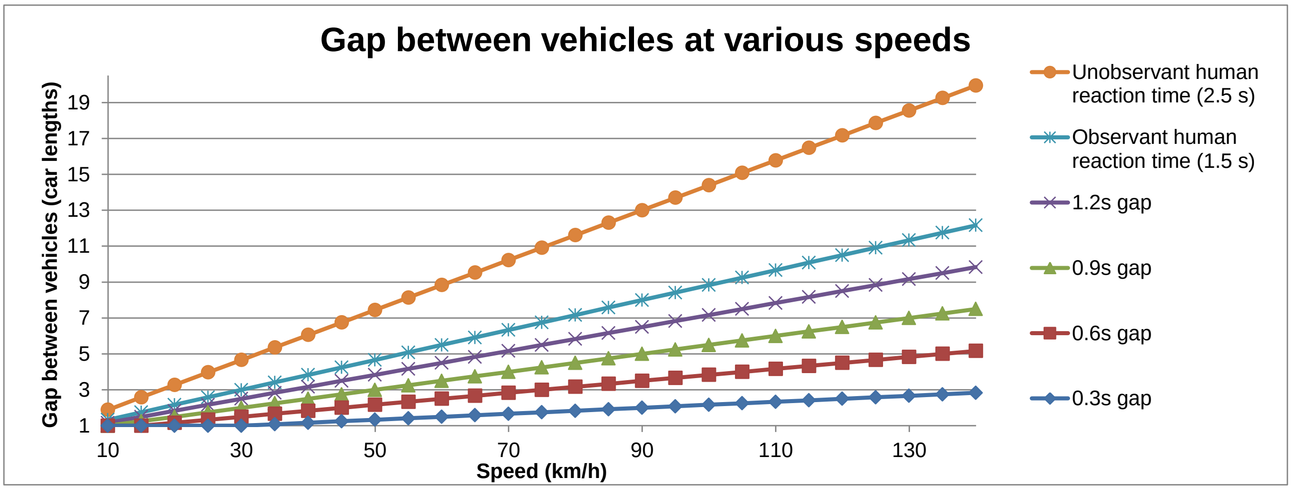

Figure 16 shows the gap between cars at various speeds and how they relate to reaction times. An alert driver has a reaction time of approximately 1.5 seconds, while an inattentive driver's reaction time is approximately 2.5 seconds. When this reaction time is removed from the system, the gap between vehicles will relate more to human comfort (i.e. how close to the vehicle in front do we feel comfortable being) and physics (i.e. how long it will take the vehicle to stop).

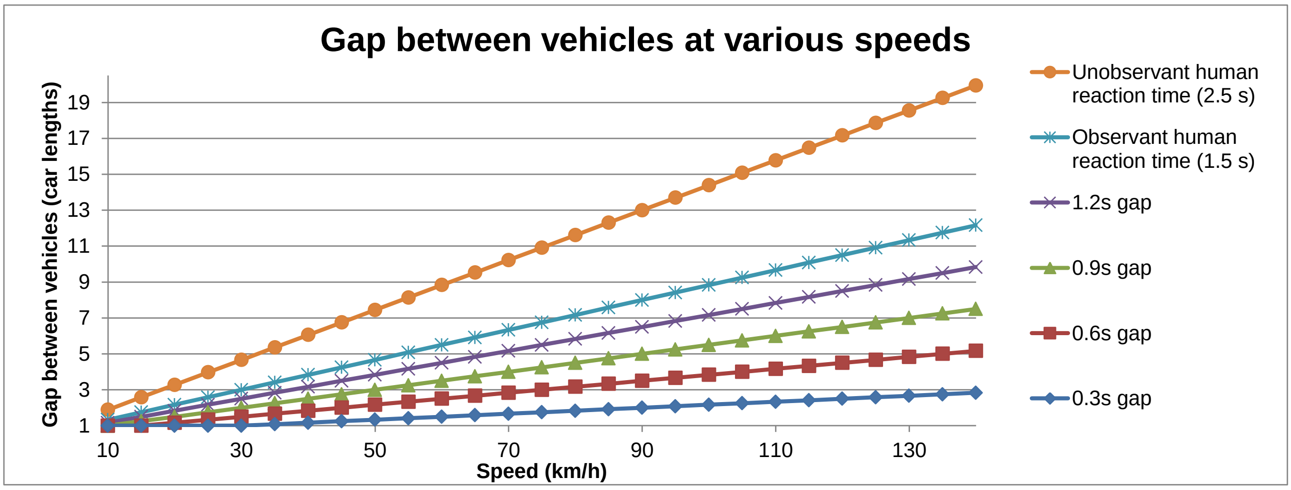

Figure 16 Vehicle gaps at various speeds.

In an unconstrained environment (such as modern fenced freeways), the reduced gaps between vehicles will also increase the freeway capacity. The Highway Capacity Manual provides that the functional capacity of a freeway is 2250 pcu/la/h for target Level of Service E at 80 km/h. This equates 1 vehicle every 1.5 s and a density of 28 veh/km and a gap of 30 metres. By reducing this gap to 0.9 s

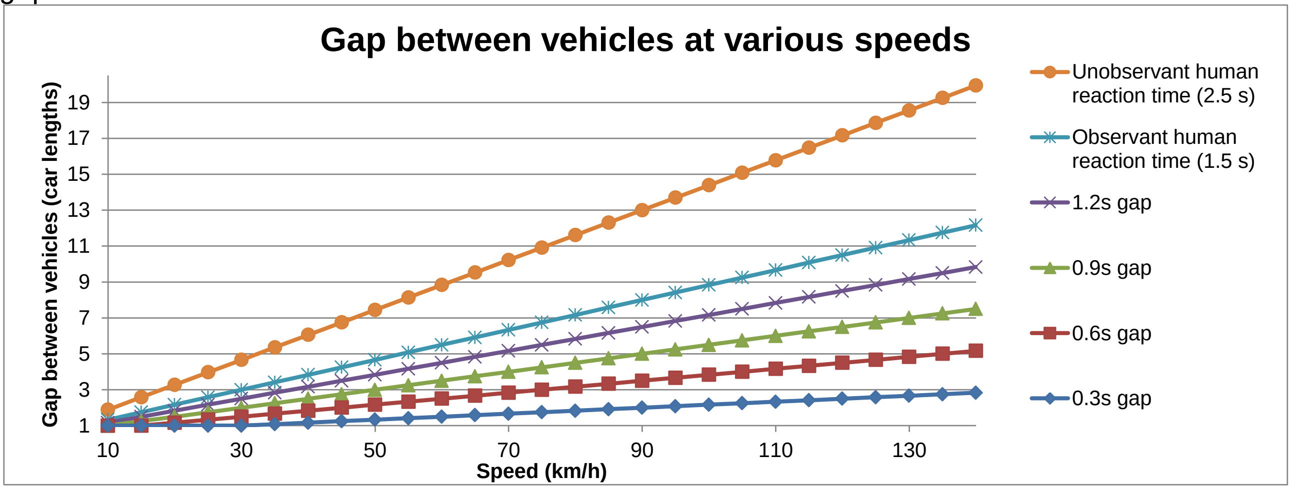

Figure 16 shows that for the same vehicle gap (approximately 6 vehicles) the operating speed can increase to up to 120 km/h. Using the speed / density relationship:

q = k * v where q is flow (pcu/h), k is density (pcu/km) and v is speed (km/h)

the equivalent flow can increase to 3360 pcu/hr or a 50 percent increase in throughput and travel time on the freeway.

Transport demand in Australia is expected to double between 2015 and 2036[22]. Measures such as ride sharing, reducing vehicle size and automated roads will increase net capacity, while increasing mobility, more pedestrian priority areas and increased mobility (including circulating autonomous vehicles) and population growth will increase demand and congestion.

Figure 13 suggests how the combination of effects of the transport system changes may result in both increased capacity and demand as population grows.

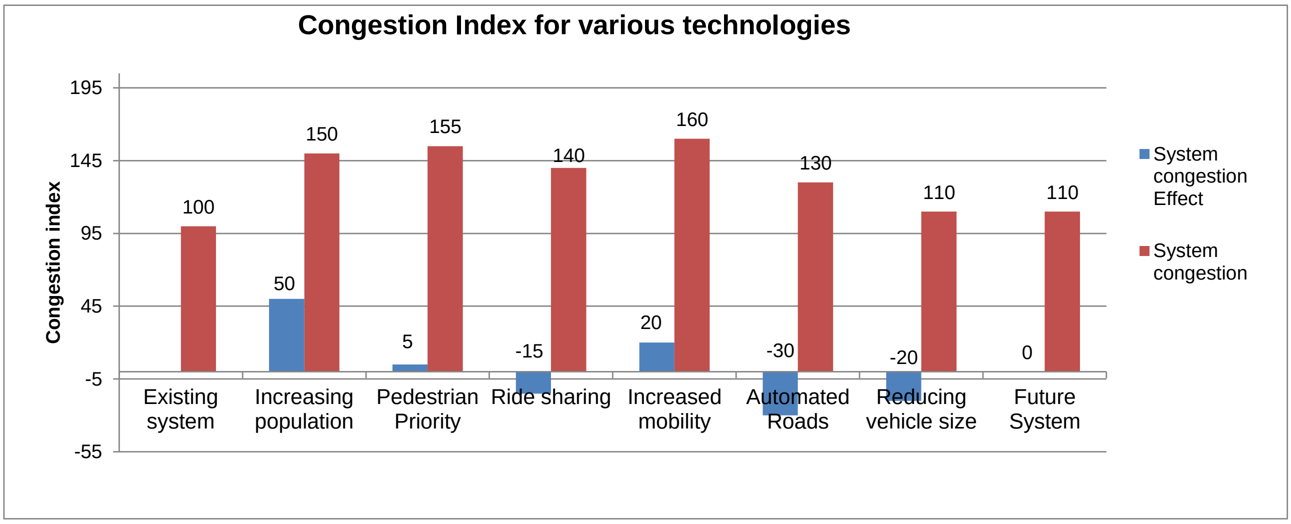

Figure 17 Congestion index as technology changes

TRAFFIC MANAGEMENT

Fully autonomous cars, with the current safety systems are designed to protect pedestrians and cyclists. This is partly for insurance reasons, but also to ensure that autonomous vehicles are not banned through an over-reaction. As the numbers of these vehicles increase, pedestrians will become increasingly aware that they can "hack" the system by stepping out in front of the cars. The stopping distance for an autonomous car at 40 km/h is 28 metres (at 3.5 m/s^2). In CBD environments, this has the potential to turn all roads into shared zones with absolute pedestrian and cyclist priority.

For autonomous vehicles to operate in the urban environment, they will need to know the difference between a bicycle on the road and one on cycleway or footpath and the rules around pedestrian priority. Figure 18 shows how the Google car has its rules set up for Mountain View, California.

In urban environments, with C-ITS, it is theoretically possible for traffic signals and street signs to be removed as proposed by Volvo[23]. However, under these circumstances, pedestrians and cyclists would not know when it is safe to cross the road as vehicles would apparently randomly stop and start. As a result, traffic signals will need to remain – if only to inform pedestrians.

---

[22] *Infrastructure Australia Audit 2015*, Infrastructure Australia, Canberra Australia, 2015
[23] Volvo Drive Me project, https://www.youtube.com/watch?v=EMD_0SjzTcA, viewed 29 September 2015

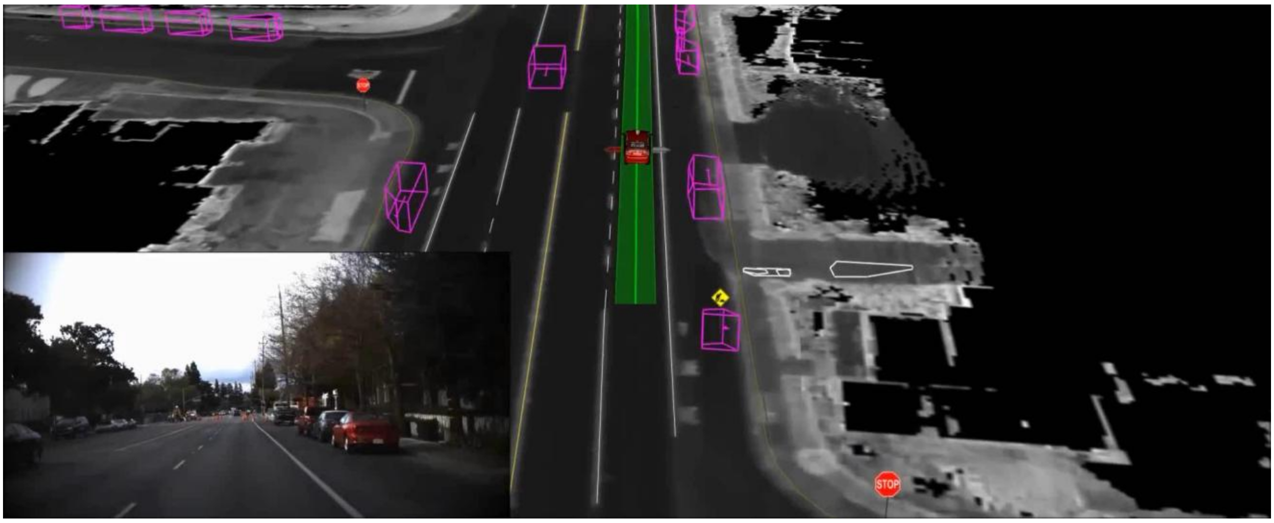

Figure 18 Screen Capture of the Google car navigating the streets (Google 2015)[24]

URBAN DEVELOPMENT AND ROAD HIERARCHY

Until the development of the motor vehicle and the requirement to dedicate land for parking, housing was built in compact forms. Currently traffic assessment guides for developments such as the *Guide to Traffic Generating Developments, ITE Trip Generation Manual* and TRICS require large amounts of parking. With autonomous vehicles parking off-site or being for short term hire, the amounts of parking being provided will need to be reconsidered. When ramps, driveways and circulation aisles are included, the amount of land required per 10 m^2 parking space can increase to 30 – 40 m^2. The site highlighted in Figure 19 is 9.9 ha, of which 3.4 is dedicated purely to car parking.

Autonomous vehicles arriving at a site can drop their passenger off and then park in compact stacking parking (horizontal or vertical) or travel off site to make other trips or go to a storage location.

Figure 19 Costco and bulky goods showrooms in Casula, NSW Australia (Six Maps)

[24] https://www.youtube.com/watch?v=lxKdUIEECN8, viewed 29 September 2015

When the roads and parking function is reduced to pick up / drop off and storage, a large amount of existing road space will be freed for other uses. On local streets, this will allow more footpath activities such as outdoor dining and increased space for cycleways and parks. The community will need to decide for each part of the road network its function in an autonomous network as for each jurisdiction, the autonomous vehicle will require an understanding of the road rules and road hierarchy in order to make decisions about route choice and its impacts on the local community and travel time and cost.

Table 1 shows a simplified version of the existing road hierarchy. This hierarchy has served planners and engineers for the last 50 years. However, should pedestrians "hack" the system, there is a risk that the commercial imperatives of autonomous vehicles push towards fencing pedestrians away from the road and fining them for intruding into road. To ensure that the new system remains human focused, I propose an alternate hierarchy that balances the community and movement functions. This is shown in Table 2.

Location	Function	Priority
Local Street / CBD	Access	Pedestrians / bicycles / public transport / deliveries
Collector / Distributor Road	Access / Transition / Traffic	Public transport / Freight distribution
Sub Arterial	Transition /Traffic	Intra city movement
Arterial	Traffic	Intra city movement / high volume
Motorways	Traffic	Inter City movement / high volume / high speed

Table 1 Existing road hierarchy (simplified)

Location	Function	Priority
Local Street / CBD	Human scale movement	Pedestrians and bicycle priority
Lower activity urban streets	Access / Transition	Pedestrians / bicycles / lower speed autonomous vehicles (30 km/h speed limit)
Collector / Distribution Street	Transition	Pedestrian areas separated from roadway by cycleways / wide verges / bus ways
Automated Roads	Traffic	Intra city movement / high volume
Motorways	Traffic	Inter City movement / high volume / high speed

Table 2 Potential future road hierarchy (simplified)

THE ROLE OF TRAFFIC ENGINEERS AND TRANSPORT PLANNERS

The role of traffic engineers and transport planners will be critical during the transition period and after. New jobs working with software developers and car manufacturers to understand and interpret road rules and design manuals will be required for each jurisdiction. Transport and traffic planners and urban planners will need to review the entire road network to ensure that self-driving and autonomous vehicles do not result in fencing off roads and replacing on-street parking with more lanes to increase capacity.

CONCLUSION

The transportation industry is changing at pace that is hard to fathom. Engineers and planners are struggling to keep pace with the developments in self-driving and autonomous vehicles. In order to not be in the position of the fixed telephony industry with the advent of mobile phones, we have an opportunity to position ourselves in the centre of this new and exciting industry and should embrace the change that is coming.

ACKNOWLEDGEMENTS

The author would like to thank GHD PTY LTD and David Kinniburgh, Stephen Thompson and Grant Wood of GHD in particular for their support in enabling the author to developing this paper.