Collective technologies: autonomous vehicles

Working Paper

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24 February 2015

This working paper contributes to Securing Australia's Future (SAF) Project 05.

Contents

Overview

- An autonomous vehicle describes a vehicle that includes a set of technologies which enable tasks to be performed with little or no human input.
- An autonomous vehicle is a collection of individual technologies. There are many different features and functions that provide different levels of autonomy in the motor vehicle.
- Categorisation of autonomous versus non-autonomous is no longer helpful. Autonomous features have been gradually added to motor vehicles over many decades and this is likely to continue.
- The individual components that make up the autonomous vehicle will diffuse independently of each other. The interdependence on other factors make it difficult to predict which technology will advance and be adopted, and how quickly.
- New vehicle technologies can take up to thirty years to reach full adoption across the vehicle fleet. It will take many decades to see ubiquitous change in vehicles.
- Cars are part of the existing transport system and infrastructure, and it is difficult to find sudden changes in any large (infrastructure) system. It is more likely we will see incremental change.
- The amount of electronics in the car is increasing and information and communications technology (ICT) is the key enabling technology of autonomous functions. ICT makes it possible for automated functions to be added onto the existing motor vehicle and existing transport infrastructure.
- Automotive manufacturing standards and legislation that mandate the inclusion and use of new vehicle technologies can reduce the time taken to reach full adoption of such technology across the vehicle fleet.
- Increased automation in the motor vehicle does not require radical new regulations. Existing laws and legislation can cope with autonomous vehicle technologies.
- The functions of an autonomous navigational system can be achieved without in-vehicle automated features. Smart infrastructure and a smart device (such as a phone) in a car could achieve the same outcome.
- Whether or not the technology for safe and reliable autonomous vehicles becomes available, society has a choice in its adoption.
- The motivation for the development of the autonomous motor vehicle is to address human safety, environmental harm and congestion. Framing these problems around autonomous vehicle technologies can prevent decision makers from putting effort into a broader range of solutions, both technical and non-technical.

1. What is an autonomous vehicle

The term *autonomous vehicle* describes a vehicle that includes a set of technologies allowing it to perform complex mobility tasks with little or no human intervention. Autonomous vehicles include:

- personal motor vehicles or driverless cars
- unmanned autonomous vehicles (UAV), commonly known as ‘drones’, which can be controlled remotely or operate autonomously
- planes operating with autopilot
- light rail driverless trains (metros)
- autonomous mining trucks and machines.

Using increasingly sophisticated artificial intelligence and robotic technologies, an autonomous vehicle can perceive its environment and make decisions that enable it to travel without human input. Autonomous motor vehicles are of great interest for their potential to reduce car accidents, traffic congestion and pollution. The focus of this paper is on the autonomous motor vehicle.

1.1 Autonomous vehicle: a collective set of technologies

An autonomous vehicle is a vehicle that includes a set of technologies which enable tasks to be performed with little or no human input. Table 1 outlines a set of in-vehicle autonomous technologies, their function and technical requirements.

Feature	Function	Technical requirements
Lane departure warning system	Sense lane and road boundaries to stay in the lane and avoid a crash	Embedded magnetic markers in the road and/or accurate GPS and/or image processing
Lane keeping assist system	Vehicle makes adjustments to steering in order to stay in the lane	On board sensors – radar, LIDAR, ultrasonic range finders, image processing
Parallel parking assist	Vehicle assists with parking by steering (driver controls speed)	Rear view camera, control steering
Rear parking assist	Vehicle assists with parking and brakes to avoid crashing	Ultrasonic range finders in rear bumper, image processing, radar
Adaptive cruise control	Vehicle assists driver by controlling speed by assessing distance from other objects and controlling braking	Sensors, radar, LIDAR, braking and throttle control systems
Driver monitoring system	Monitor driver alertness and provide warnings; if unheeded the vehicle will brake	Cameras, sensors, eye tracking software, braking control system
Traffic sign recognition	Vehicle reads traffic and speed signs, traffic lights	Camera, image processing
Collision avoidance system	Warn driver when there is an impending crash, may take over controls	Sensors, lasers, braking and throttle control systems
Night view assist system	Assist driver in seeing in darkness or poor weather conditions	High resolution liquid crystal display, image processing
Adaptive headlights	Vehicle adapts to external conditions and steering direction	Sensors, lasers, light control system
Airbags	Vehicle deploys airbags on impact	Sensors, airbag deployment
Antilock braking system	Automated system that prevents the wheels locking up and unavoidable skidding	Electronic stability control, sensors, steering control, throttle and brake control
Navigation system	Real-time geographical data received from several GPS satellites to calculate longitude, latitude, speed and course to	In-vehicle GPS, digital maps, communications or individual device (e.g. SatNav, mobile phone) including GPS, digital maps, communications

	help navigate a car without human control .	
Networked communication system	Vehicle to vehicle communication, vehicle to infrastructure communication (vice versa)	In-vehicle or device with GPS, digital maps, communications Also data security, reliable and secure network communications, communication standards, wireless capabilities

Table 1: Examples of autonomous vehicle functions Source:(Forrest and Konca 2007) and wikipedia

An autonomous vehicle requires a range of technologies to sense and monitor the behaviour of its external environment and to take action where required. It must be able to process the broader surroundings to rapidly plan and adjust to unexpected situations. Key technologies include:

- A combination of sensors used to make sense of the external environment, gathering information regarding distances to other objects and allowing vehicles to more accurately pinpoint their location
- Processing the data captured from these technologies to extract relevant information on which to base decisions and manage the interaction between the human driver and computer
- Mechanical control systems that perform the desired action of braking, accelerating, turning
- Communication and networking: vehicle to vehicle, vehicle to infrastructure, pinpointing location
- Smart infrastructure that will be required to provide a feedback loop of data to inform optimal decision making.

Table 2 provides examples of the components required to develop an autonomous vehicle.

Sensors	Data processing	Mechanical control systems	Communication	Infrastructure
Laser sensors	Sensor processing - object recognition	Driving wheel control	Vehicle to vehicle communication	Physical infrastructure
3D cameras	Decision making	Brake control	Vehicle to vehicle communication, vehicle to infrastructure communication	Predictive models
Radars (LIDAR)	User interface	Throttle control	GPS, digital maps	Optimisation
Ultrasonic sensors	Sensor processing		Data security	Networking
GPS, digital maps	Optimisation			Maintenance and monitoring
Traffic sensors	Computational behavioural economics		Infrastructure to network	Dynamic traffic planning/ toll setting

Table 2: Components of autonomous vehicle technology Data sourced from (Forrest and Konca 2007)

The technologies required by an autonomous vehicle are based on information and communication technologies. Over the past 30 years, the addition of electronic control devices and software has made significant innovations in automobile manufacturing possible. Computers are used to control simple functions such as windshield wiper action through to high level engine management.

Throughout the 1990s advances in sensors and actuator technology resulted in computers taking a more active role in the mechanical operation of the car (Walker, Stanton et al. 2001). The cost of electronics in luxury cars can account for 23% of total manufacturing costs and an estimated 80% of innovation in car manufacturing is now attributed to electronics {Leen, 2002 #3568. The autonomous vehicle is an example of how ICT has become a general purpose technology and in particular its ability to complement existing vehicle technologies to offer a new function in personal mobility transport. ICT makes it possible for automated functions to be added onto the existing motor vehicle and existing transport infrastructure or to address the problems in other ways that are not necessarily embedded in the vehicle.

1.2 Autonomous vehicle or vehicle with automated features?

The motor vehicle has progressively advanced and improved its performance over the past century. Automation has been slowly introduced into cars since the early 1900s. Every decade sees the introduction of more automation. As each feature is introduced gradually, it can very quickly begin to feel just like a natural part of driving (Knight 2013).

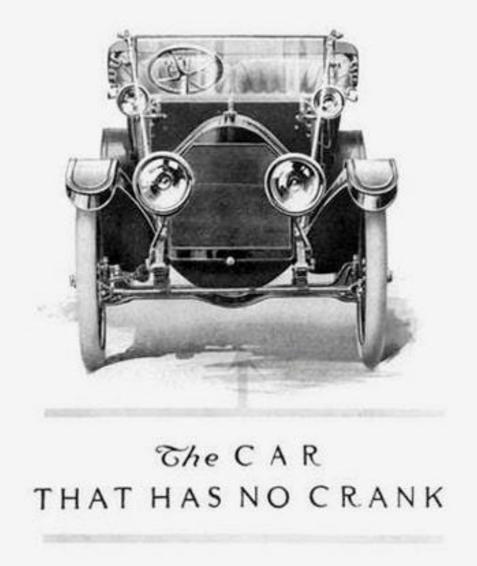

Figure 1: 1912 model Cadillac became the first car to replace the hand crank with an electric starter motor

Table 3 illustrates the time taken from initial invention of some in-vehicle automated technologies to their use within the first car, and then wider adoption.

	Invented	Patent	First car	Wider adoption
Power steering	1876	1900	1951 (Chrysler)	
Airbag	1941	1951	1967 (Chrysler)	Full adoption in new cars by 2002[1]. Still not mandatory in Australia[2]
Intermittent wipers	1963	1964	1969	
Antilock braking system	1958 for motorcycle		1970 (Ford)	Mandatory in the EU since 2007

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[1] Gargett, D., M. Cregan and D. Cosgrove (2011). The spread of technologies through the vehicle fleet. Australasian Transport Research Forum 2011 Proceedings, Adelaide, Australia.

[2] http://acrs.org.au/about-us/policies/safe-vehicles/airbags/

	(1929 for aircraft use)			
Electronic cruise control	1968	1968		1980s
Electronic stability control	1987		1992 (BMW)	70% adoption in new cars in 2010[3]. Mandatory in Victoria since 2011[4].
Adaptive cruise control[5]	1990	1991	1995 (Mitsubishi)	

Table 3: Automated vehicle technologies: invention to adoption timelines Source Wikipedia unless otherwise specified

New vehicle technologies are slow to diffuse throughout the whole vehicle fleet, even when the safety benefits are clear. New technologies are usually incorporated into new cars over a period of 10-15 years, and it can take up to 15 years before adoption in over 90% of the vehicles on the road is reached (Gargett, Cregan et al. 2011).

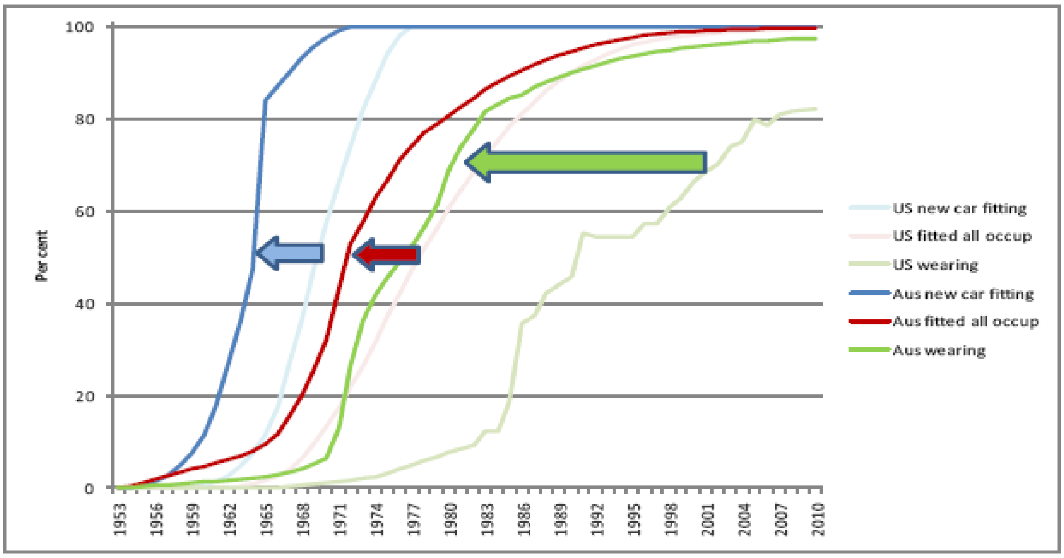

Figure 2: Australian and US seatbelt adoption curves. Source (Gargett, Cregan et al. 2011)

Australia was at the forefront of introducing seat belt technology. Seatbelts for driver seats were made mandatory in all new vehicles sold in 1965. As a result, Australia's adoption curve was many years in advance of the US. Victoria was the first jurisdiction in the world to introduce mandatory seatbelt wearing laws in the 1970s. This resulted in an acceleration of uptake but even with this regulation, it took thirty years for 90% diffusion through the vehicle (Figure 2). Airbags and electronic stability control show similar adoption curves. It took nearly nine years for front airbags to be installed in most new vehicles and 90% adoption is on track to occur in 2020 (Figure 3). Current legislation in Australia should also mean that all new cars will include electronic stability control by 2014, with 90% adoption predicted in the 2030s (Figure 4) (Gargett, Cregan et al. 2011).

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[3] Gargett, D., M. Cregan and D. Cosgrove (2011). The spread of technologies through the vehicle fleet. Australasian Transport Research Forum 2011 Proceedings, Adelaide, Australia.

[4] http://www.howsafeisyourcar.com.au/Electronic-Stability-Control/

[5] http://www.businessinsider.com.au/how-adaptive-cruise-control-will-change-driving-in-america-2012-8

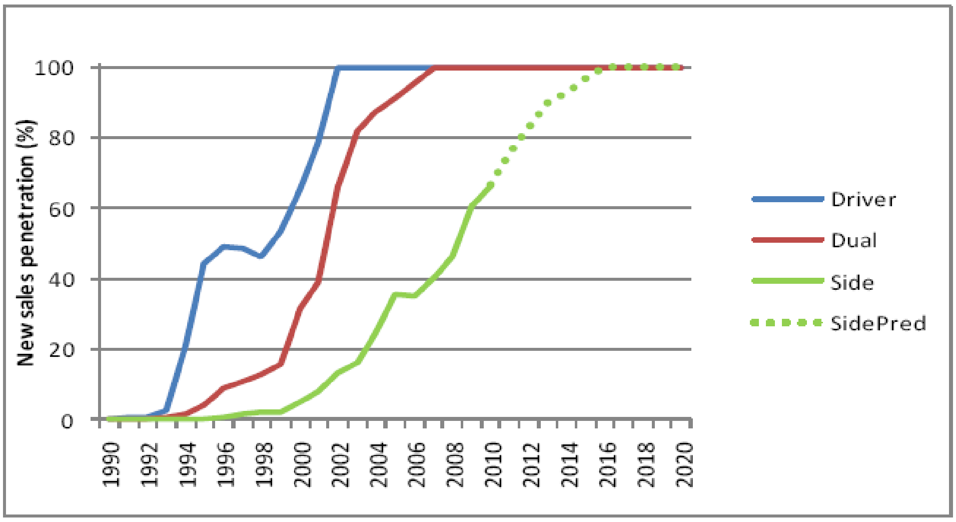

Figure 3: Airbag adoption curves, new cars/SUVs source:(Gargett, Cregan et al. 2011). Note: this graph shows adoption within new cars, it does not show adoption across the entire vehicle fleet on the road.

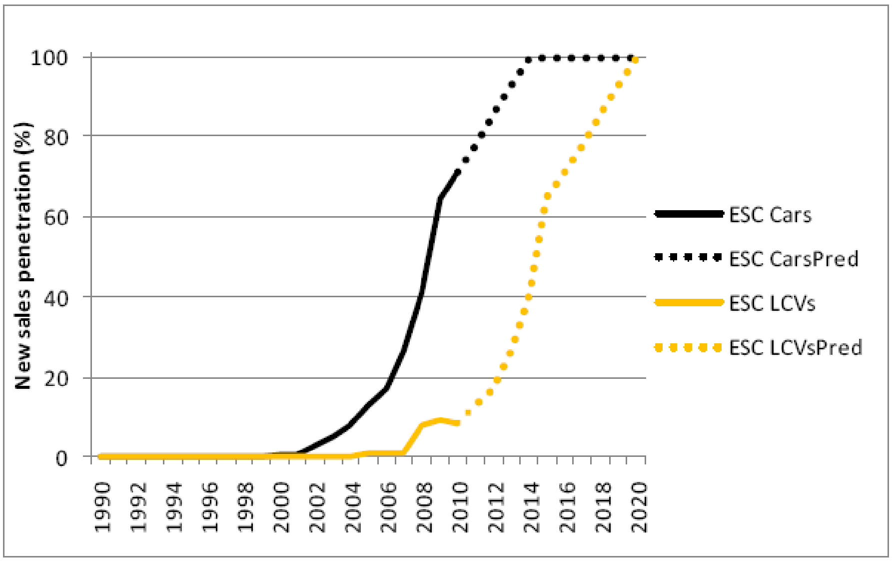

Figure 4: Electronic stability control adoption curves, new light vehicles Source:(Gargett, Cregan et al. 2011). Note: this graph shows adoption within new cars, it does not show adoption across the entire vehicle fleet on the road.

A number of interdependent forces influence the development and adoption of any technology. From the time a new technology is available for inclusion in new cars to its full adoption across the whole vehicle fleet may take up to thirty years. We see similar timelines for the adoption of seatbelts (Figure 2), airbags (Figure 3) and electronic stability control systems (Figure 4) in vehicles. Legislation regarding the inclusion of the technology and its use can help reduce the time taken for diffusion (Gargett, Cregan et al. 2011).

As a collection of many different individual components – that individually may take up to 30 years to diffuse across the entire vehicle fleet on the road – the *autonomous vehicle system* is likely to encounter numerous issues and a very long timeframe before it can reach its full promise.

1.3 Tackling each technical challenge

From a technical perspective the autonomous vehicle will depend on research and development in sensors, data processing, mechanical control systems, communication and smart infrastructure (Table 2). It is extremely difficult to predict which of these technologies will have the greatest impact or will be developed more quickly. Some technologies may race ahead of others, depending on external factors. For example, the gaming industry drove advancement in computer graphics hardware, which has been crucial for image processing. Others may take longer to reach the required level of technical performance.

It is estimated that 93% of motor vehicle accidents are due to human error {NHTSA, 2008 #3570}, (S.Carra 2013). This is the motivation for increasing automation in motor vehicles. To gain public trust it will be important for autonomous vehicles to demonstrate they are capable of making complex judgements as well as, or better than[6], a human driver. For all of the faults of human drivers – they are distracted by other passengers, use mobile phones, speed and may drive when tired or intoxicated – there are many accidents that humans avoid. The processing abilities of a human are difficult to replicate in a computer. A human driver anticipates the actions of other road users and is able to quickly modify his or her own driving to avoid collisions. Drivers watch the body language of pedestrians and other drivers. They monitor the speed and action of cars that are several cars ahead to anticipate sudden braking.

> *According to my cursory analysis (which uses a Poisson distribution and assumes the accuracy of the national crash and mileage estimates), Google's cars would need to drive themselves (by themselves) more than 725,000 representative miles without incident for us to say with 99 percent confidence that they crash less frequently than conventional cars. If we look only at fatal crashes, this minimum skyrockets to 300 million miles. To my knowledge, Google has yet to reach these milestones.*
>
> Driving at Perfection by Bryant Walker Smith Assistant Professor in the School of Law and (by courtesy) in the School of Engineering at the University of South Carolina. Posted on March 11, 2012 at 3:20 pm The Center for Internet and Society[7].

Technological progress is needed in the field of sensors and artificial intelligence. Complex algorithms that can process the external environment in real-time, make the appropriate judgement, and follow through with the correct action are required for automated tasks. Technology that enables autonomous cars to deal with these complex situations could take a long time to become affordable and compact enough to be included in commercially available cars. Sensors, lasers, navigation systems and computers in existing prototypes are currently too expensive to be deployed widely. For example, the LIDAR- based system that allows the Google car to create a 360-degree view costs $70,000. The rate of adoption will most likely increase once these technologies become more affordable (Silberg, Wallace et al. 2012). The likelihood of a significant decrease in the production cost of LIDAR technology needs to be treated with some scepticism. Achieving such a massive reduction in cost may require radical design changes. It is possible that different technologies will be developed or improved to replace the LIDAR. In any case, one can be reasonably certain that until the cost comes down substantially, such autonomous vehicles will not become widespread (Brynjolfsson and McAfee 2014, Raghnaill and Williamson 2014).

1.3.1 User interface technology: the interaction between the autonomous system and driver cognition

Taking technology of user interface as an example, this section outlines a range of issues illustrating the many challenges that need to be addressed with this single component. This is only one component of a large set of components that will continue to add higher degrees of autonomy in vehicles.

As autonomous vehicles evolve, the role of the human driver will be redefined. Drivers will be expected to assume a supervisory role and take control of the car as soon as the autonomous system reaches its limits. The interface between the driver and the car is very complex. The system

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[6] In some cases there is an expectation for new technologies to bear zero risk before they replace existing technologies (which can bear even more risk). Refer to Attitudes chapter.

[7] http://cyberlaw.stanford.edu/blog/2012/03/driving-perfection

must be able to predict when it is about to reach its limit and require manual intervention. This prediction will need to be made in enough time to alert the driver who may take several seconds to react and take over.

Drivers will not be required to perform driving functions at all times and will likely become more disengaged from driving. Cognitive science research on distracted driving suggests this may be a significant safety challenge. When a car has some level of autonomous control, human driver reengagement will pose another key challenge. To experience the greatest benefits of autonomous technology, human drivers will want to engage in other tasks while the vehicle is driving autonomously. With shared control the driver is more likely to remain engaged in the task, reducing delayed response time (Merat and Lee 2012). The driver may become complacent and slow to intervene when using a partially autonomous system. However, the driver will be expected to quickly reengage (in a matter of seconds or less) at the vehicle's request.

As autonomous systems develop they become more complex, and their workings become more opaque to the people who operate and manage them. People are shifted to high level supervisory tasks and long term maintenance instead of hands-on contact and experience (Reason 1990). The more human drivers depend on automated driving, the less practice the driver has to develop the skills required when the automated system disengages. In the 1980s psychologist Lisanne Bainbridge identified this as the 'irony of automation'. That is, the more advanced the car becomes, the more crucial it may be for the unskilled driver to intervene during failure. The irony described refers to the designer who deliberately tries to remove the human from the process but still leaves tasks that cannot be automated to the human in case of emergency (Bainbridge 1983).

Increasing reliance on autopilot technology has been blamed for reducing the manual flying abilities of pilots. A 2011 draft report commissioned by the Federal Aviation Administration suggests an over-reliance on automation may have contributed to several crashes involving pilot error. Safety experts are seeing cases in which pilots who are suddenly confronted with a loss of computerised flight controls do not know how to respond immediately, or they make errors. The report found that in more than 60% of accidents and 30% of major incidents, pilots had trouble manually flying the plane or made mistakes with automated flight controls (Lowy 2011).

Ironies of automation still exist in the design of automated systems. As technology increases in its complexity there is more interaction between computers and humans, and the resilience of the systems will rely on operators as the last line of defence when the technology inevitably fails in ways that designers were unable to anticipate. Humans are inherently flexible and adaptable, however their ability to 'save the day' will depend on training, skills and the real time availability of useful information (Baxter, Rooksby et al. 2012).

Google is attempting to address this issue. Initially the Google car was built with a mechanism to return control of the steering wheel to the driver in case of emergency. However when Google found drivers were distracted and slow to respond in emergencies, they began to investigate taking the driver completely out of the driving process (Markoff 2014). Such a leap in degree of automation will not only pose serious technical but also legislative challenges – such a vehicle would not meet existing legislation in California, for example, which requires a human driver to be able to take immediate physical control if needed (Barr 2014).

2 Addressing concerns that arise as the level of automation increases

As discussed in earlier sections, the adoption of any one vehicle technology will depend on multiple factors and in the past has been shown to take up to thirty years before full adoption. Some of the factors affecting the adoption of autonomous vehicles will depend on the complex relationship people have with their cars, attitudes toward automated machines and the future options available for personal mobility.

People can find themselves stressed by the idea of autonomous technology – the belief that the technology does what it wants independent of human direction (Winner 1978). In the 1950s and 1960s automated cars on automatic highways were popular predictions. Driving was predicted to become more passive, dream cars would allow owners to watch TV or catch up on work as they travelled around the city. In the 1950s, just as Americans were being enticed by automation in their cars, homes and public transport, they were nervously waiting to see the effect automation would have on people's jobs and happiness (Corn and Horrigan 1996).[8]

History indicates that, in general, people are relatively comfortable adopting automated machines when there are benefits to be gained in safety or convenience. People have come to accept many automated and automatic technologies in their everyday lives (Table 4).

Decade introduced	Automated/automatic system
1910	Autopilot in commercial planes
1910	Traffic lights (US)
1920	Automatic toaster
1920	Automatic elevator doors
1930	Automatic washing machine
1950	Electric automatic kettle
1960	Airbags in cars
1960	Automatic train operation (with driver) London Underground
1970	Antilock brake system in cars
1980	Robotic surgery
2000	Copenhagen driverless metro (no driver)

Table 4:The introduction of some common automated and automatic systems , source Wikipedia, 2014

Some automated features in these cars are already commercially available e.g. adaptive cruise control, lane departure warnings, collision avoidance, parking assist, in-car navigation. Several manufacturers are currently building and testing a range of autonomous vehicles – Audi, BMW, Ford, Toyota, Volvo (Fagnant and Kockelman 2013).

The following section addresses how language, trust and ethics play an important part in how people perceive different levels of autonomy in machines.

2.1 The role of language

It is worth considering the language around autonomy and how that might influence the way people perceive these technologies. The word autonomous originates from the Greek *autonomos*, meaning 'having its own laws'. The Oxford English Dictionary defines *automate* as a process or facility to be operated by largely automatic equipment. Similar definitions are offered for *autonomy* and *automatic* as they relate to machines:

> *Autonomy - Of a machine, apparatus, etc.: capable of carrying out, without supervision, tasks typically performed by humans.*

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[8] Read more on technology and work in Discussion Paper: Technology and Work

> *Automatic - Of a machine, appliance, etc.: that does not require an operator; that works by itself under fixed conditions, with little or no direct human control.*

The term 'autonomous' vehicle may mislead, and consequently foster unnecessary concern among potential adopters. Autonomous describes acting independently however most of the functions of the autonomous vehicle will rely on a person in the driver's seat (in case of emergency), communication with other vehicles, and central traffic systems. In a recently released report on the role of autonomy in Department of Defense systems, the US Defense Science Board Communication argues the design and operation of autonomous systems should be considered in terms of human–system collaboration. The word autonomy can invoke images of computers making independent decisions and uncontrolled action. The report points out that in reality, military autonomous systems are supervised by human operators at some level, and 'autonomous systems' software embodies the designed limits on the actions and decisions delegated to the computer (Defense Science Board 2012).

When assessing the adoption of autonomous vehicle technologies it is worth considering whether semantics and folk-definitions have a bearing on some of those concerns about self-determination and moral choice, particularly in passenger vehicles.

2.2 Trust in computers

Trust is an important part of adopting any new technology. Although concern is expressed by some when talking about the fully autonomous systems, the gradual introduction of automated features in the car is widely accepted.

> *'The real truth is that when the motor comes into universal use life will not be worth living. … A horse does not like to run a man down if he can help it, but a machine of steel and brass will delight in killing people.'(The Argus 1900)*

Surveys investigating public trust in autonomous vehicles continue to show mixed results. A survey of 1000 people conducted by ORC International for the *Chubb Group of Insurance Companies* revealed that less than 20% of people said they would buy an autonomous car. Almost 70% said they would *not* feel safe in a driverless car, while less than 25% said they would feel confident allowing a loved one to be a passenger. The survey indicated that people are more accepting of autonomous technologies that provide assistance in potentially dangerous situations. Between 70-90% of people surveyed said they would pay extra for safety and convenience features like collision warning and adaptive cruise control (Beissman 2013).

In contrast to these results a *Cisco* survey of 1,500 consumers across ten countries found 57% of respondents would be "likely to ride in a car controlled entirely by technology that does not require a human driver". However, only 46% would allow their children to ride in a driverless car (Autosphere 2013).

These studies indicate some level of trust in autonomous vehicles but there are a range of risk factor factors at play in the perception of this new technology. The introduction of a new automated system can lead to a sense of fear and distrust. Giving up control to an unfamiliar piece of technology evokes a whole range of risk perception responses – lack of trust, lack of control, increased perception of uncertainty and risk (Ropeik 2010). The perception of risk has been known to drive policy decisions and lead to delayed implementation of new technologies. This may be the case for autonomous vehicles if the technology is held to a higher standard of safety than that of human drivers.

Another struggle for individuals assessing the benefit of autonomous vehicles is understanding the degree to which they are better off with the new product compared to the existing product. This is particularly tricky when the safety benefits that autonomous vehicles promise include the reduced risk of a possible future harmful event (Rogers 2010). The seat belt is one of the most important preventative innovations in the car however there are still people who do not wear seatbelts. Although Australia is well recognised in the international community for its high seatbelt wearing rates (Fleiter, Lewis et al. 2013), in NSW in 2012 13% of car occupants killed on the road were not wearing seatbelts [REF ROAD CRASH STATS in NSW). Given the complex difficulties in perceiving the benefits of preventative innovations it may take a long time before the general public is ready to pay for autonomous features that promise reduced risk.

Today there is public acceptance of auto-piloted planes and trains and we may learn from their implementation. In some cases the risk perception of automated transport has been carefully managed. Planes are still under the supervision of human pilots (who rely heavily on autopilot) and the Ansaldo Breda Driverless Metro implemented in Copenhagen in 2002 is also not strictly unmanned. Although the trains operate without on-site human involvement there are central control rooms monitored by people and metro stewards located on trains give passengers a sense of safety (Fich 2002). To facilitate an increase in the level of public trust of autonomous vehicles, regulators and automotive manufacturers will need to consider a range of dimensions:

- managing common risk perception factors
- understanding the role of language and expectations of an autonomous system
- managing the transition to an autonomous system by retaining some level of human control or support within the system
- building ethical and moral considerations into the decision making tools used by vehicles.

Those anxious about the introduction of automated machines ignore the fact that the adoption of any new technology depends greatly on social factors, and societies do have a choice.

The ethics of autonomous systems

Ethics are often a topic of debate when discussing autonomous systems in a military environment but this topic is now of interest to those building the autonomous personal vehicle.

Any autonomous system developed will on occasion malfunction, and unpredictable conditions on the road will lead to accidents that may also be fatal. Car accidents usually occur with very little notice and it is true that a human may not necessarily be able to assess the situation and make a better decision than any computer. However the key difference between the decision making process of the human driver compared to the in-vehicle computer is that the human driver will make their decision in real time, the vehicle computer will make its decision based on a set of rules defined by a programmer ahead of time. The ethical dilemma relates to how the computer will decide the best plan of action and the rules that will inform these decisions (Goodall 2013).

If a collision is inevitable then an autonomous vehicle needs to quickly calculate the best collision outcome. How to define the 'best outcome' is the challenge. If a collision can be avoided by the vehicle there is a clear choice to be made. However, if a collision is inevitable the computer must decide on the best course of action. If the computer is programmed to choose an option that injures the least amount of people, does that mean it should sacrifice the life of its passenger in order to save multiple others?

How does the public perceive drones?

If the number of stories in the media is any indication, there is a great deal of interest and anticipation in drones. A 'drone' is the popular name adopted for an Unmanned Aerial Vehicle (UAV). An UAV is usually controlled by a human operator via remote control.

The first pilotless aircrafts were built during and shortly after World War I. Drone attacks have been common in more recent wars such as the Afghanistan war. The machines are used to gather information and in some cases to perform the end action but the ultimate decision always lies with the human operator in the chain. UAVs have traditionally been used for military purposes but more recently other industries are finding new applications for drones.

Google, Amazon and Domino's Pizza have shown interest in 'drones for delivery' that could deliver products directly to the consumer. The Australian textbook rental service, *Zookal,* has partnered with drone delivery service, *Flirtey*, looking to the Civil Aviation Safety Authority (CASA) for approval to use a drone for delivery of books in populated areas. In Australia, civilian operators are allowed to fly UAVs if they comply within regulated safety rules (Grubb 2013).

Drones are also used for observation of the environment, performing aerial surveying of wildlife and used in emergency situations like bushfires. Autonomous underwater vehicles map the ocean floors and marine life. For example *Argo floats* measure temperature and salinity of the ocean, providing data for ocean health and climate research and prediction (IMOS).

Although there is increasing usage of drones for civil, military and commercial applications there are still many safety, security and legal issues to resolve (House of Representatives Standing Committee on Social Policy and Legal Affairs 2014).

3 The role of regulation

Although owning and driving a car gives people a sense of freedom, it is actually a heavily regulated activity. Drivers need to be trained, registered and insured. There are many rules, regulations and laws that govern what people can and cannot do when driving. Seatbelt, drink driving laws and speed limits regulate driver behaviour. Cars are built to strict safety and performance standards. They are tested, registered, inspected and insured.

When it comes to the development and adoption of autonomous vehicle functions, regulation can take many forms. Regulation and industry standards play an important role in the design of high performing, reliable and compatible technologies required for an autonomous vehicle system.

Regulating for the inclusion of new technologies in new vehicles can shorten the timeframe for adoption. However as demonstrated, even when the seatbelt was made compulsory in new cars and its use was mandated, it took up to thirty years to achieve 90% saturation point in the vehicle fleet (Gargett, Cregan et al. 2011).

Existing laws and will be tested as autonomous vehicles shift responsibility away from the human driver. In general, where technological change poses a challenge for existing legal rules and frameworks, the dilemmas are frequently solved (Moses 2011). A look at the road and criminal laws in Queensland finds that most of the existing laws are adaptable to the introduction of autonomous vehicles although some will require modification (Tranter 2015). Regulations can adapt where required as each individual component is added to the autonomous vehicle. The RAND Corporation has investigated the ability of the US liability system to cope with autonomous vehicle technologies and found the existing regulatory system does not present any unusual liability concerns for car owners or drivers. However there may be a greater effect on car manufacturers and insurers (RAND 2009, Anderson, Kalra et al. 2014).

3.1 What can we learn from the implementation of other autonomous systems?

There are many automated systems that people trust their lives with. It may be useful to look at examples of other systems as increasing levels of autonomy are introduced.

Some comparison with increasing in-vehicle automation can be made with robotic surgery, a more recently introduced (semi) autonomous technology. A surgical misadventure can have serious consequences, causing death or injury to the patient. Robotic surgery litigation is complex and manufacturers in this field are aware that robot malfunctions resulting in patient injury could lead to a products liability lawsuit. Product liability cases that involve computer devices (and therefore metadata) are entitled to use the information collated as evidence. The metadata is comparable to the black box used in airplane crashes. It has been found that for most surgical misadventures, the manufacturer can use the data collected. In many situations the evidence would point to human error by surgery staff. Applying this principle to manufacturers of autonomous vehicle technologies, one of the best defences for liability may lie with a similar metadata black box (McLean and Waxman 2010).

Elevators offer an example of a technology that has shifted from manual operation to automatic operation without human involvement. Because elevators were classified as common carriers, operators and manufacturers were held to a higher duty of care. A common carrier shares the characteristics of public transport, that is, it engages in transportation services for the public where passenger safety is not within the control of the passenger. The introduction of automatic elevator technology was accompanied by changes in insurance policies and increased regulation. The creation of elevator liability insurance and adoption of industry safety standards aided the uptake of automatic elevators (LeValley 2013). It is possible to see how an autonomous vehicle could also be classified as a common carrier.

Another important type of regulation is that of safety and performance standards. Air bags are one of the ore recent automatic safety technologies installed in cars. While they are reported to have save many lives, air bags did not initially live up to original expectations. In 1977, regulations for air bags were based on the estimated 9,000 lives saved per year. In reality, air bags saved a total of 8,369 lives in the fourteen years between 1987 and 2001. This was partly due to the fact that air bags were designed to protect an unbelted adult male passenger in a head-on collision. Unfortunately the design put some passengers of smaller stature at risk due to the extreme force that is necessary to meet the performance standard of protecting the unbelted adult male passenger. These unintended consequences led to many improvements and changes to standards and regulations, making air bags safer (Anderson, Kalra et al. 2014).

These examples demonstrate the public is willing to put their trust in automated systems when there is benefit to be gained. But the introduction of these systems needs to be carefully managed using liability laws, regulation, safety standards and performance standards. In the case of autonomous vehicles it will be important to set performance and safety standards that will work for all categories of drivers and passengers in a range of conditions in which the vehicle will need to operate. Drivers and manufacturers may also need to come to terms with the use of a black box system that captures data in the event of a collision.

3.2 The role of regulation and liability laws in the adoption of autonomous vehicles by industry

Most technologies sit comfortably within existing legal frameworks that regulate the liability of manufacturers, retailers and consumers (Moses 2011). Comprehensive studies by the RAND Corporation have found the existing liability regime in the US does not present any unusual liability concerns for car owners or drivers of autonomous vehicles. With the expected decrease in the number of crashes it is likely both drivers and insurance companies will be keen to adopt autonomous vehicle technology. However, the liability of manufacturers would increase as they could be held responsible for malfunctions (RAND 2009, Anderson, Kalra et al. 2014).

3.2.1 The car manufacturing industry

The significant difference between conventional automotive technologies and autonomous technologies is that autonomous technologies sense and make judgments about the vehicle’s external environment on behalf of the driver. For technologies at the lower end of the automation spectrum, drivers retain some control of the vehicle at all times – e.g. driver-warning systems and adaptive cruise control. In this case, performance and safety standards can specify a smaller set of environmental conditions since the driver will ultimately be responsible for interpreting the environment and determining whether the autonomous functions in the vehicle should be used.

However, vehicles that perform more complex tasks with greater levels of autonomy will require standards and testing that span the *entire* range of conditions in which the vehicle might be expected to operate safely.

The external environment and conditions on the road system can vary greatly. The performance requirements of sensors and systems that detect and process this dynamic external environment will be extremely important. Software upgrades will be challenging as they will need to be compatible with earlier models of vehicles and sensor systems. And as more vehicles include autonomous features, software and other system upgrades will have to perform on increasingly diverse platforms, making reliability and quality assurance all the more difficult (Kalra, Anderson et al. 2009).

This shift of driving responsibility from driver to vehicle means that car manufacturers may be held responsible for collisions caused by malfunctions. They could be held liable for systems that leave the driver in total or partial control, especially if drivers are able to claim they were misinformed about the true capabilities of the system. Products liability law has proven to be adaptive to new technologies and there is no reason that the legal system will not be able to address any problems as they arise (Villasenor 2014).

Studies by the RAND Corporation recommend reducing manufacturer liability by setting uniform regulatory standards and integrating a comprehensive cost-benefit analysis into the standard for liability. If autonomous features are shown to decrease accidents then a cost benefit analysis should take into account the potential benefit of installing these features into the car. By including the benefit of autonomous systems in any cost benefit analysis, the manufacturer liability could be reduced (Anderson, Kalra et al. 2014).

In addition, the use of a black box system that gathers data could also be used to reduce liability of the car manufacturer. As discussed earlier, manufacturers of surgical robots successfully use metadata to protect themselves from liability where some human involvement is expected. The use of a black box system does raise some privacy concerns i.e. will a driver or manufacturer want the vehicle data recorder used against them in court?

Cars are more than just a means of transport to many people. Vehicle owners have strong feelings and emotional attachments to their cars. Consumers consider how a new vehicle will reflect their personality, making a statement about who they are. While lifestyle requirements and budget restrictions are also a consideration, how the new vehicle makes one feel weighs heavily into the equation (Road and Travel Magazine 2012). The automobile manufacturing industry must take into consideration what the consumer wants. Different makers offer different classes of car with different functions and aesthetics. These features are marketed as an expression of individual freedom, status, nostalgia and representation of lifestyle choice. The complex nature of people's relationship with cars means that any significant changes in the road transport system will depend on the interaction between community benefit, technology development and individual psychology.

Jim Pisz, corporate manager of Toyota in North America believes Toyota customers are conservative "They tend to have a fairly long adoption curve"… "It was only five years ago that we eliminated cassette players".

On the other hand Mercedes, whose cars are built for people who love to drive, has a reputation for innovation. Will taking their hands off the steering wheel defeat the purpose?

Source: (Bilger 2013)

3.2.2 The car insurance industry

If autonomous vehicle technologies successfully reduce the number of collisions then it is possible the need for specialised car insurance will lessen. The decrease in the probability of collisions and the associated lower insurance costs could encourage the adoption of autonomous technologies by drivers and insurance companies (Anderson, Kalra et al. 2014).

However, although safer autonomous vehicle may lead to fewer accidents on the road, it is possible the severity of accidents could increase if vehicles are operating at higher speeds. This change in severity of collisions, from more accidents at low speed to fewer accidents at higher speed, may affect how insurance companies insure against them. It is easier for an insurance company to calculate the expected cost of many small crashes than the less probable larger events (Kalra, Anderson et al. 2009).

4 Does the technological vision match reality?

Much of the fundamental technology required to build autonomous vehicles is available and advancements in the performance of the technology are progressing quickly. Some autonomous features are already commercially available in cars, e.g. advanced driver assist systems, adaptive cruise control, lane keeping and parking assistance. The Google driverless car is often cited as an impressive example of how the autonomous vehicle is within close reach of the public. The Google car is reported to have travelled over 500,000 km. In the UK, the *Induct Technology Navia* is a driverless car that is now commercially available for $266,000AUD (Stansfield 2014).

These are exciting developments and can lead us to imagine a thrilling new world of personal mobility options. But the promise of the autonomous vehicle will not be easily fulfilled. As illustrated in Table 1 and Table 2, the features of an autonomous vehicle rely on a range of technologies. The rate of development and adoption of the autonomous vehicle will depend on the rate of development and adoption of each technical component. The development of each individual component will depend on multiple factors including technological advancement, market dynamics, cost and regulation of each individual component.

4.1 Predicting the future

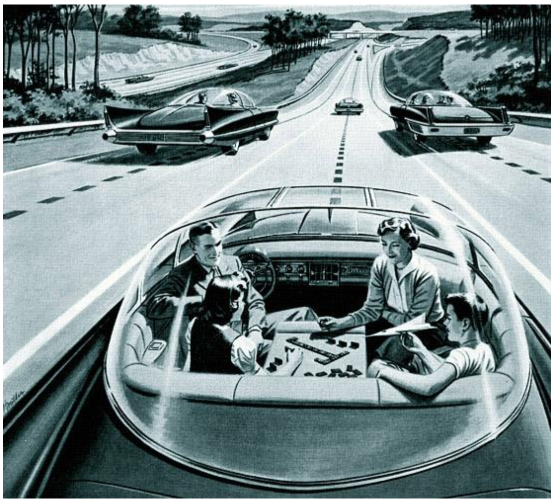

Figure 5: Autonomous car 1956. Source: (America's Power Companies mid 1950s)

Autonomous vehicles are greatly anticipated because of their potential to reduce car accidents, traffic congestion and pollution. Since cars have been on our roads there have been many predictions about the availability of the driverless car. Many predictions place the magic year about twenty years after the year of prediction. That is, predictions in the 1950s saw driverless cars on the road in the 1970s, predictions in the 1990s marked the early 2000s and more recent predictions promise autonomous vehicles on the road by 2035 and 2050.

Past predictions

In the 1956 Motorama auto show, General Motors produced a musical short film, *Key to the Future,* which predicted self-driving cars in the far-off future of 1976. Check it out….https://www.youtube.com/watch?v=FKlkePb-tTg

From Electronic Driving in the Future published in 1958. Driving will one day be foolproof, and accidents unknown, when science finally installs the Electronic Highway of the Future. Some day in the future when you drive on to a superhighway, you'll reach over to your dashboard and push the button marked "Electronic Drive." Selecting your lane, you'll settle back to enjoy the ride as your car adjusts itself to the prescribed speed. You may prefer to read or carry on a conversation with your passengers – or even catch up on your office work. http://blog.modernmechanix.com/electronic-highway-of-the-future/

In *The Age of Spiritual Machines* (1999), Ray Kurzweil predicted that in the year 2009 "Intelligent roads and driverless cars will be in use, mostly on highways."

Past experience shows it is near impossible to predict future technologies, particularly those that predict a system of aggregated technologies like the autonomous vehicle. It is extremely difficult to predict when each component will reach the required performance level and – even then – how much of an impact each component will have.

Predictions by car manufacturers and consultancy firms (paid by industry) tend to be very optimistic about the implementation of autonomous vehicles on roads. It is common for forecasters in industry to be seduced by technological wonder. Forecasters fall in love with the technology, suffering optimism bias which may cause them to lose perspective of other considerations such as the long lag for delivery of improved technology performance and the willingness of the market to adopt (Schnaars 1989). Such predictions could also be viewed as promoting self-interest when creating such hype will certainly not harm investment and support for further R&D.

In contrast, the academic community is more restrained in its predictions, believing that the technology to respond to a more complex and uncertain environment (urban driving) is a long way off. However, many projections overlook how technically challenging it is to make a driverless car. There are still many computer science and artificial intelligence challenges to meet in advancing each individual component of the autonomous vehicle (Knight 2013). Much of the hype associated with autonomous vehicles is based on an overestimation of what is actually possible with the technology. Some commentators take it for granted that 'strong AI' is just around the corner. There is very little evidence of this, and there are such enormous uncertainties regarding whether it is possible even in principle (Raghnaill and Williamson 2014). Academic experts are often cautious about the prospects of a fully autonomous car, predicting such vehicles will be limited to specific and well controlled settings such as construction sites where there are low speed limits and minimal traffic. It is overly optimistic to assume that the technology challenges associated with robotic cars are solved (Gomes 2014).

Technology predictions are often predicated on a number of common assumptions. Firstly, that 'new' technology is revolutionary, when in fact most innovations progress incrementally from previous inventions. History shows that technology developments and the manner in which they are adopted are gradual. To date, in-vehicle technologies have taken many decades to progress from initial invention to diffusion (Table 3). As illustrated earlier in this paper, once a new vehicle technology is adopted in its first new model car it can take up to thirty years to see full adoption (defined here as 90% or greater) across the whole vehicle fleet on the road (see Section: Autonomous vehicle or vehicle *with automated* features). Secondly, predictions assume social continuity – that the problems and priorities in the future will be the same as those in the present. Although it may be difficult now to foresee a time when the personal motor vehicle will not exist, it does not mean it cannot happen. Finally, the focus on a technological fix can deter decision makers from putting effort into a broader range of solutions, including non-technical solutions (Corn c1986).

5 Avoiding the narrow 'technological fix' approach

Along with the great benefits that motor vehicles have brought, there have been some serious disadvantages. Motor vehicle accidents kill and injure millions of people around the world each year. The World Health Organization (WHO) reported approximately 1.24 million deaths occurred on the world's roads in 2010 (WHO 2013). In Australia, 1,310 people died in road accidents in 2012 and over 52,000 people were treated in hospital for transport related injuries (BITRE 2013), (AIHW 2013).

Autonomous vehicles are desired because of their potential to reduce car accidents, traffic congestion and pollution[9]. But there is a real danger that by viewing the broader problems through the technology specific lens of autonomous vehicles, we might be missing other opportunities to address these problems (Moses 2011). There are a range of proven strategies to reduce deaths and congestion on our roads. The National Road Safety Strategy 2011–2020 outlines a path for national action on reducing fatal and serious injury crashes on Australian roads by addressing the safety of roads, speeds, vehicles and drivers (Australian Transport Council 2011). And there are potentially a range of other technical solutions that are not in-vehicle technologies. The following section explores just some of the solutions that can be used to address the problems motivating the development of the autonomous vehicle.

5.1 Getting people off the road

One obvious way to reduce congestion is to get less people to use roads during peak times. One option is to increase travel on public transport. Others include encouraging people to work from home or to avoid high traffic areas.

5.1.1 Teleworking

In 2012, the ABS reported approximately 7 in 10 people (71%) aged 18 years and over travelled to work or full time study primarily by passenger vehicle. This could have been either as a passenger or a driver. Only 16% of Australians used public transport, while 4% walked and 2% cycled (ABS 2013).

Not being able to access public transport is one of the main reasons for people to use passenger vehicles to get to work or study. In 2012, of adults who travelled by passenger vehicle to work or study, over half (53%) stated that a lack of public transport services (at all, or at the right or convenient time) was one of the main reasons for not taking public transport. Over a quarter (28%) preferred the convenience, comfort, or privacy a private vehicle provided.

In a 2012 national survey conducted by Australian Work and Life Index program, 16% of respondents worked at home on a regular basis (Skinner, Hutchinson et al. 2012). Working from home is increasingly enabled by new technologies and growth in jobs where work can be completed away from the workplace.

5.1.2 Using congestive pricing

Pricing strategies have been shown to be a very effective tool in managing congestion in the long term (Sorensen, Wachs et al. 2008). Congestion pricing assumes that making drivers pay for the negative externalities of driving will result in behavioural changes. A survey performed by Sydney

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[9] For more on the problems that autonomous vehicles hope to solve refer to

Appendix 1: Motivation for the development of autonomous vehicles.

University's Institute of Transport and Logistics Studies suggested a five cent per kilometre congestion charge on major roads at peak hour would lead to 22% of drivers choosing to travel outside of peak periods and 13% moving to using public transport. The institute concluded peak pricing would encourage people to select different times for travel and ease congestion on main roads (news.com.au 2013).

Congestion pricing can also reduce pollutants. In simulation trials it was found that a ten cent per kilometre user charge imposed on the main road network in Sydney between 7am and 6pm would reduce CO_2 emissions from passenger cars by 4.74% by the year 2015(Beck 2013).

Land available for parking is also of concern to many local governments. Parking-related traffic contributes to 30% of congestion, as vehicles circle around their destination to find an available place to park (Zhao, et al., 2012). A parking detection and guidance system could be used to acquire real-time data of available parking spaces for road users, decreasing congestion to some extent.

5.2 Building safer cars

The impact of a car crash is what causes the most damage to the occupants. The metal frame offers some protection from injury when an accident occurs. Cars are designed so the structure distributes the force over the entire frame, allowing the impact to be absorbed. The level of protection depends on the car. Studies have shown the bigger and heavier the car the safer it is for the occupants. Unfortunately this doesn’t align with the desire to reduce harm to the environment by driving lighter, smaller and more fuel efficient cars. In his book *20% Chance of Rain*, Richard Jones asks why car manufacturers are not expected to provide this information when we purchase a new car. When we purchase food we look for information regarding health benefits; when we purchase appliances we look at the star rating for information regarding energy efficiency. If people in small cars are twice as likely to be killed as those in larger cars, why isn’t that information provided to consumers up front so that an informed risk choice can be made? (Jones 2012).

In addition to the car frame, the restraint used in a vehicle can help people survive the impact of a crash. V-strap harnesses used by pilots can withstand 45.4g of force because the pressure is distributed evenly over the stronger body surfaces such as the hips, thighs and shoulders instead of concentrating in the solar plexus area[10]. The addition of the seatbelt to the motor vehicle has played a crucial role in saving lives. But there currently exists a restraint that could protect occupants to an even greater extent.

5.3 Navigational devices

The US National Highway Traffic Safety Administration (NHTSA) provides a categorisation of the level of in-vehicle autonomous technologies. The NHTSA categories describe the different levels of human and autonomous interaction from Level 0/1 (vehicle with little or no automated functions) to Level 4 (fully autonomous vehicle which performs reliably and safely in all situations) (NHTSA 2013).

Whilst categorisation of the level of autonomy may help industry and regulatory bodies, as with any general categorisation it can break down upon closer examination (Bowker and Star 2000). There is a risk that framing the solution around such categories will deter decision makers and manufacturers from thinking outside the box and looking for solutions not embedded in the vehicle. For example, the navigational functions of an autonomous vehicle could be achieved with the use of a mobile phone located in the car.

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[10] John Paul Stapp was a U.S. Air Force officer who pioneered studying the effects of acceleration and deceleration forces on humans by using himself as a guinea pig. He tested his body’s ability to withstand increasing amounts of g force http://en.wikipedia.org/wiki/John_Stapp

Approximately 7.5 million Australians were reported to use the internet via their mobile phone during June 2013 (ACMA 2013). To address congestion on the road, the use of the smart phone could allow for similar capabilities to those of an autonomous vehicle system. Volvo has trialled a smartphone application to instruct the vehicle to park once the driver exits the car. The car manoeuvres into a parking space and sends a message to the driver informing them of its location. The driver can collect the car in person or use the phone to request the car comes back to where the driver was dropped off (The Economist 2013).

It may be possible to connect all vehicles (autonomous or not) with a smart transport infrastructure system using a separate device like a smartphone in the vehicle. The navigation system, data processing and networking could be contained within the device, allowing the navigational functions to be performed without any in-vehicle technology. Such a solution would not require retrofitting cars and could lead to faster diffusion.

5.4 Managing driver behaviour

Despite the known dangers, as a society we seem prepared to accept the risk of the personal motor vehicle. Drivers weigh up the road design, the amount of traffic, accident rates, car performance and levels of enforcement.

Certain behavioural factors continue to be implicated in many serious casualty crashes. The proportion of deaths and serious injuries on the road that result from behavioural factor are listed below. Note these categories are not mutually exclusive i.e. more than one factor can be involved in any one incident.

- Speeding is involved in 34% of total deaths and 13 % of total serious injuries
- Drink driving is involved in 30% of total deaths and 9% of total serious injuries
- Drug driving is involved in 7% of total deaths and 2% of total serious injuries
- Restraint is involved in 20% of total deaths and 4% of total serious injuries
- Fatigue is involved in 20-30% of total deaths and 8% of total serious injuries (Australian Transport Council 2011).

5.4.1 Strategies to decrease speeding

Drivers are often willing to accept the increased likelihood of death or injury to enjoy the benefit of shorter travel times (Jones 2012). A study conducted by OECD and the European Conference of Ministers of Transport in 2006 concluded that speeding is the number one road safety problem in most countries and that reducing average speeds by 5% would reduce facilities by 20%.

A reduction from 110/115 km/hr to 99-97 km/hr is predicted to reduce fatalities up to 54% and reduce injury crashes by 6%. In urban roads, a study in 2001 prepared for the Australian National Road Transport Commission found that a 10 km/hr reduction in speed (from 60 to 50 km/hr) would prevent 8000 casualty crashes per year while increasing average travel time per trip by only 26 seconds (Archer, Fotheringham et al. 2008).

Speeding can be managed using a number of different methods:

- Reducing speed to better suit the design of the road
- Speed humps, traffic signals, signs, one way streets
- Driver awareness through updated signs about road and weather conditions
- Use of intelligent speed adaption device. Such speed limiters are used in large trucks in Australia and Europe. These can warn drivers if they are speeding, or can physically limit the speed of the vehicle.

- Driver attitudes and awareness of the dangers and risks of speeding (Archer, Fotheringham et al. 2008).

5.4.2 Seatbelt ignition interlock

The seatbelt is one of the most important preventative innovations in the car however there are still people who do not wear seatbelts. Mandating the use of seatbelts has resulted in a very high rate of seatbelt use. Although Australia is well recognised in the international community for its high seatbelt wearing rates (Fleiter, Lewis et al. 2013), an estimated 28% of vehicle fatalities in Australia are not wearing seatbelts (Australian Transport Council 2011). Preventative innovations, such as preventing smoking, or using safety features within a car such as a seatbelt, can have a slower rate of adoption because they are offering a lower probability of an unwanted future event (Rogers 2010).

In 1973 the US National Highway Traffic Safety Administration (NHTSA) required that all new 1974 passenger vehicles should be equipped with an ignition interlock that allowed the vehicle to start only if the driver was seated. In addition, an audible warning was activated if seat belts were unfastened during the trip. However this requirement was not well received by the public and the US Congress passed legislation prohibiting the NHTSA from requiring either the ignition interlock or continuous buzzer systems (Transportation Research Board of the National Academies 2004). The standards that exist today still only produce a short warning message (lights or beeping) to the driver.

5.4.3 Alcohol interlock device

An alcohol interlock device uses a breath tester connected to the ignition of a vehicle to stop it from starting when alcohol is detected. Alcohol interlock programs have had some success in changing the behaviour of serious offenders (Transportation Research Board of the National Academies 2004). In Queensland the alcohol interlock program came into effect in 2010. Currently the system only applies if the driver is committed and convicted of a drink driving offence of 0.15 blood alcohol level, if the driver has been charged with dangerous driving while affected by alcohol, or if the driver has received two or more drink driving charges in the space of five years (Department of Transport and Main Roads 2014). There is scope to extend the use of such a device to high risk drivers.

5.5 Future personal mobility options

Australia is currently a nation reliant on cars. In 2012, approximately 7 in 10 people (71%) aged 18 years and over travelled to work or full time study primarily by passenger vehicle. Only 16% of Australians used public transport, while 4% walked and 2% cycled. The ABS predicts with an increasing number of passenger vehicles, this high level of passenger vehicles use is likely to continue (ABS 2013).

Once given the opportunity of the freedom, flexibility and versatility of personal vehicles, citizens seem reluctant to compromise these benefits regardless of the risks (Ruthven 2012). In the early years of automobile production, many people were unable to afford cars, which soon became a status symbol of the wealthy (as is still the case). But will the car remain a symbol of freedom and status? What type of relationship will people in the future have with their car regarding access versus ownership, the new values of the next generation and the car as a status symbol? Status can just as well be reflected in the ownership of an autonomous vehicle as it can for cars today. Perhaps the attraction to freedom associated with owning a car will be replaced by the attraction of not being responsible for a car and using integrated transport options such as car-sharing (Beiker 2013).

Over the past five years, the Car Sharing Providers industry in Australia has grown rapidly; revenue is expected to grow at an annualised 25.0% to total $43.1 million during 2013-2014. This has been partly due to the increased cost of crude oil prices and the demand for cost-efficient and convenient inner-city transport. The industry has also greatly benefited from advancements in mobile technology and the internet (IBIS World 2013).

Conclusion

At present most of the cars on the road include some automated functions that can help the driver with complex tasks. It is reasonable to expect a gradual increase in the degree of autonomy across a wide range of vehicles but this is unlikely to occur at a fast or constant rate. The future may see vehicles with a high degree of autonomy, just as there may continue to be vehicles with little or no autonomy for a very long time.

There are some exciting technology developments and a great deal of anticipation by the public, media and automotive industry about the driverless car. However it may be overly optimistic to assume that technology challenges associated with autonomous vehicles are solved. The features of an autonomous vehicle rely on a range of technologies and the rate of development and adoption of each component will be difficult to predict.

Even when the technology for a fully autonomous vehicle is developed, it doesn't mean that society will choose that path to solve problems related to personal transport. We may instead choose to use the improved visual processing, data processing and mechanical control systems to help us become safer drivers, as is the case with anti-lock braking and electronic stability control systems. Or perhaps we will not rely on personal motor vehicles in the future. History shows we cannot assume social continuity – the problems and priorities of today may not be those of the future. Just because a technology exists, does not mean society will adopt it.

As technologies increasingly perform complex driving functions, the responsibility will shift from the driver to the vehicle. Existing legal rules and frameworks can usually cope with the challenges of technological change. As the level of autonomy increases, negotiating the risks to achieve the benefits of autonomous vehicles will require some policy and legislative decision making. As technology performance advances and we see the level of autonomy increase it is possible that some of the existing regulations and rules around driving and driver behaviour will disappear and be replaced by performance and safety standards.

Finally, it is important to remember what problem is being solved. The main motivation behind the development of the autonomous vehicle is to increase road safety and reduce congestion. By viewing these problems through the technology specific lens of autonomous vehicles opportunities to solve these problems may be missed. Non-technical solutions and solutions that are not necessarily in-vehicle technologies may also provide the desired outcome.

Appendix 1: Motivation for the development of autonomous vehicles

The motivation for developing the personal autonomous vehicle is to increase road safety, improve traffic flow, decrease the environmental impact of cars and make personal transport more accessible. In addition, autonomous vehicles have a range of potential applications in commercial, research and consumer sectors.

Road Safety

The social problem of automobile safety has been a high priority since the 1960s in the US when several publications called attention to the high rate of motor vehicle fatalities (Rogers 2010). Even though the number of cars on the road has continued to increase the number of deaths on the road in Australia has continued to drop from its peak of 3798 in 1970 (Shapcott 2010), (Fleiter, Lewis et al. 2013). Over time, reductions in fatalities have been achieved by the introduction of safety regulations in car manufacturing, building of safer roads and introduction of regulations and campaigns to change driver behaviour. The OECD Road Safety Annual Report marks 2012 as a record year, with figures showing the lowest fatalities on record for most of the 32 OECD countries that participate in the International Traffic Safety Data and Analysis Group. The report attributes much of the decrease to improvements in vehicle design and equipment, speed management, effective drink driving policies and higher rates of seatbelt (OECD 2013).

Despite these decreases the number of deaths and injuries on our roads is still too high. The World Health Organization (WHO) reported approximately 1.24 million deaths occurred on the world's roads in 2010 (WHO 2013). The 2004 WHO report on road traffic injury prevention cited between 20 million and 50 million people were injured or disabled on the road. In Australia, 1,310 people died in road accidents in 2012 and over 52,000 people were treated in hospital for transport related injuries (BITRE 2013), (AIHW 2013). And the annual cost to the Australian economy of road traffic accidents is estimated at $27 billion(Department of Infrastructure and Regional Development 2014).

> *One day people may wonder why earlier generations ever entrusted machines as dangerous as cars to operators as fallible as humans.*
>
> Clean, Safe and it Drives Itself, *The Economist*, April 20 2013

An estimated 93% of traffic accidents are caused by human error (NHTSA 2008), (S.Carra 2013). Difficult conditions, such as darkness, rain, fog, and driving when tired or distracted or under the influence of drugs and alcohol, all impair human ability to driver safely. Autonomous vehicles aim to improve safety by removing human error (Hayes 2011).

Some autonomous features have been shown to increase driver safety by systems that are currently helping drivers avoid accidents (Forrest and Konca 2007). A US study published in 2012 found that partly autonomous features in existing cars do help to reduce crashes. The study, conducted by a not-for-profit funded by the auto industry, indicates that cars with forward collision warning systems which either warn the driver about an impending crash or apply brakes automatically, are involved in few crashes than cars without these features (Knight 2013). In the US, the Insurance Institute for Highway Safety (IIHS) has estimated that if all vehicles had forward collision and lane departure warning systems, side-view assist and adaptive headlights, nearly a third of crashes and fatalities on the road could be prevented (IIHS, 2010).

Traffic flow and parking

Adaptive traffic control systems are already in use in many cities around the world. These systems use real time data to optimise timing at traffic lights, minimising stopping times and allowing more efficient traffic flow. To gain the full benefit of these systems, better communication between vehicles and the traffic infrastructure would be required. This can be an effective strategy to reduce traffic congestion to varying degrees in the short term. However pricing strategies have been shown to be more effective in the long term (Sorensen, Wachs et al. 2008).

If however congestion and parking problems decrease and ride sharing programs are made available, people may use other transport options like bicycles and public transport to a lesser degree. This could lead to an increase the number of cars on the road, or at least the number of kilometres travelled by each car. However it is the hope that the overall benefits obtained from autonomous vehicles will exceed any extra kilometres driven (Fagnant and Kockelman 2013).

Environmental impact

More recently, environmental impacts have become a high priority in society. The public is increasingly demanding more sustainable and clean energy solutions. It is now known that motor vehicles contribute to CO_2 and particulate pollution, resulting in harm to the environment and human health. The 'gross economic burden' due to transport pollution in all Australian capital cities was estimated at approximately $3.3 billion/year in 2003. In addition, the number of traffic pollution-induced deaths was calculated as marginally higher than the number of traffic fatalities in that same year (Amoako, Ockwell et al. 2003).

As more autonomous vehicles are used on the road, cars may have the ability to merge into traffic more easily and traffic could become less congested. Increased road capacity can be achieved in a fully autonomous system by allowing vehicles to travel more closely in group. It is also possible the speed limit could be increased if human error is removed. Driving at greater speeds would cut down travel time however there are concerns that when an accident does occur the greater speeds would result in more serious consequences (Forrest and Konca 2007). Vehicles can be designed to optimise fuel usage if speeds are more constant and there is less stopping and starting. The resulting improved traffic flow would also result in less fuel usage.

Accessibility and Time Saving

Autonomous vehicles can provide mobility for people who are unable to drive conventional cars. Independence can be provided to people living with disabilities like blindness, dementia, reduced mobility etc. They could provide safe and convenient transport for those currently disadvantaged and be extended to allow children greater mobility too (Folsom 2011).

In a fully autonomous vehicle, passengers may have the time to perform other tasks such as working, sleeping or eating as made possible on public transport. Removing the stress of driving could also contribute to improvements in human health.

Accessibility need not only refer to people with reduced mobility. As the adoption of autonomous motor vehicles increases, motorcyclists may find themselves at a disadvantage if similar technology is not made available for motorbikes. One of the key challenges is for autonomous vehicles to predict and adapt to motorcycle behaviour. BMW and Honda have begun to investigate connectivity technologies in motorcycles. The Adelaide-based company, *Cohda*, designs radio systems and software that will not only link nearby vehicles on the road to each other, but also to the road itself. The idea behind its autonomous car technology is to create an adaptive ad-hoc network of vehicles communicating their intentions and interacting with the infrastructure of the road.

Applications in different sectors

Autonomous vehicles have a range of potential applications in commercial, research and consumer sectors.

Sector	Potential applications
Agriculture	Monitoring animals and land, precision agriculture, crop dusting, pollination
Public services	Emergency search and rescue, border control, access to awkward locations

Media	Filming events in areas difficult to access from the ground
Delivery	Delivery of goods using drones, unmanned freight trucks
Research	Measurements of environmental conditions, marine life surveillance
Military	Intelligence gathering, reconnaissance, armed strikes
Mining	Automated trucks
Space	Mars rover, lunar probes

Source: (Yeomans 2014)

A range of professions can be potentially affected by autonomous road vehicles. The introduction of autonomous features and in-vehicle telematics in cars, trucks and buses aims to increase safety and reduce traffic flow. However the introduction of fully autonomous systems used to transport people or goods could ultimately remove the need for professional (human) drivers.

An autonomous vehicle system used to transport goods does not need to stop to sleep or eat. This can result in financial savings for freight companies and remove human error from large vehicle accidents. Driverless trucks are already common in the mining industry. In Australia's iron-rich Pilbara region, driverless dump trucks are controlled from a Rio Tinto headquarters in Perth 15,000 kms away. The key to the success of the driverless truck is its ability to operate 24 hours a day. Rio Tinto expects to have more than 40 autonomous trucks operating across three different sites in 2014 (Atherton 2013).

A report commissioned by the Australian Resources Industry Training Council in 2012 examined the extent to which automated systems are adopted in various industry sectors. The principal factors that drive a decision to adopt automation relate to:

- Resource depletion of non-renewables, increase in productivity required to remain viable
- Cost of labour, high wages for resource industry workers due to specialised nature of work. Improves productivity and reduced number of staff required.
- Resource projects are capital intensive, automation addresses this by increasing productivity.
- Integrated operations, whole of operation optimisation
- Predictable maintenance planning and scheduling
- Improved access to resources
- Precise operation leading to decreased energy consumption
- Improved OHS, removes people from dangerous situations

Car-sharing programs also offer a different business model for the transport industry. These programs seek to shift personal transportation choices from an owned asset to a service used on demand. The introduction of driverless cars can facilitate car sharing, allowing multiple passengers to use one car. In-vehicle systems could be used to improve and expand car sharing by allowing real time rentals to passengers. A 2013 study indicates that one shared autonomous vehicle can replace eleven conventional vehicles. Although the replacement vehicle is traveling more kilometres in total, the overall reduction in the number of vehicles on the road would result in reduced traffic congestion and emissions (Fagnant and Kockelman 2013).

‘Driverless’ cars on the road

Much of the basic technology required for autonomous vehicles is available, however the quality, reliability and performance of sensors, data processors and connectivity have a long way to go. The ability to trial these technologies on the road will be a crucial factor in advancing these technologies to the level required for safe and reliable driverless cars. Some of the driverless cars already on the road are:

- The US leads in this area, several states (California, Nevada and Florida) have passed legislation that allow autonomous cars to be tested on roads, however it is important to note regulations for testing the safety and reliability of autonomous features still do not exist.
- Volvo and a consortium of Swedish research institutions announced they will begin testing self-driving cars in the streets of Gothenburg in 2017. The autonomous cars will only travel on certain roads designated for the test and will involve switching between self-driving and human driving to explore the efficacy of handing back control to the driver when critical situations arise (Laursen 2013).
- In 2013, Nissan carried out the first public road test of an autonomous vehicle on a Japanese highway. The trial was run on a special pre-determined route through city streets. The trial involved demonstrating how the autonomous vehicle can assess the movement of other cars the road, in order to perform such decisions like when to stop and wait and when to continue driving.
- In December 2013, the UK government announced a review to ensure that the legislative and regulatory framework is in place so autonomous vehicles can be incorporated on Britain's roads. The government will look to offer a £10m prize to fund a town or city to become a testing ground for autonomous vehicles. By 2017 it is planned that 100 fully autonomous vehicles will run on the town's pathways along with pedestrians, using sensors to avoid collisions (BBC News 2013)

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