CONNECTED AND AUTOMATED VEHICLES: OPPORTUNITIES AND CHALLENGES FOR TRANSPORTATION SYSTEMS, SMART CITIES, AND SOCIETIES

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ABSTRACT

Connected and Automated Vehicles (CAVs) technology offers a great potential solution to massive road transport issues in the areas of safety, mobility, and the environment. For road transport, the CAV technology promises to reduce traffic congestion, increase road capacity, enhance traffic stability, and reduce vehicle emissions. However, the path to the full implementation or a high market penetration of CAVs has some critical challenges. This chapter provides a comprehensive understanding of the opportunities associated with CAVs. These include congestion reduction, road safety improvement, environment protection, societal productivity, and economic benefits. Further, this chapter discusses five major challenges, namely: transition period, economic issues, privacy and security issues, legislative issues, and ethical issues that need to be addressed before the wide scale deployment of CAVs.

KEYWORDS: Automated vehicles; Connected vehicles; Human factors; Road safety; Traffic congestion

1. Introduction

In the 71st session of the United Nations general assembly, over 170 countries came together to consider the topic on “Sustainable Development Goals (SDGs): a universal push to transform our world” (“General Assembly of the United Nations,” 2016). There are 17 SDGs in total, and the 9th and 11th goals are “Industry, Innovation, and Infrastructure” and “Sustainable cities” (“Sustainable Development Goals,” 2016). Undoubtedly, modern transportation systems will play a key role in achieving both these goals and, by extension, enable further sustainable development. However, road crashes, congestion, fuel consumption, and emissions are the major externalities of modern transportation systems, which impede sustainable development due to their enormous negative impact on mobility, economy, public health, and environment.

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Annually, more than 1.3 million road traffic fatalities have been reported globally (WHO, 2018). Beyond these serious traffic accidents, traffic congestion has a significant impact on the economy and the environment. In 2015, the annual average wasted hours per commuter in traffic in London and Los Angeles were 101 and 81, respectively ("INRIX 2015 Traffic Scorecard," 2015). For the year 2013, around 25% of CO_2 emissions were estimated to be attributed to transport globally (Olivier et al., 2013). In Australia, traffic congestion costs are predicted to rise to $30 billion by 2030, and road crashes alone cost around $27 billion annually to the national economy (BRITE, 2015). Moreover, road transport is responsible for about 16% of total greenhouse gas emissions in Australia (Ausroad, 2015). In order to achieve sustainable economic growth and environmental health globally, it is imperative that we optimise traffic operations and traffic control through technological innovations, efficient operations and control, and effective policies.

Connected and Automated Vehicles (CAVs) technology has great potential as the solution to massive road transport issues in the areas of safety, mobility, and environment ("Automated and Connected Vehicles," 2015). Experts predict that by 2030, CAVs will be mainstream, fundamentally transforming the automobile industry and how we travel (McCarthy et al., 2015). This prediction has engendered numerous studies and research programs ("Google Self-Driving Car Project," 2009; "Intelligent Transportation Systems - Connected Vehicle Pilot Program," 2015; Hawes, 2015; Hendrickson et al., 2014; Smith, 2015). Other emerging technologies such as connected vehicles (CVs) also appear promising in potentially delivering solutions at the individual vehicle and infrastructure levels.

The estimated proportion of vehicle fleet likely to be equipped for connected intelligent transportation systems (C-ITS) is 50-65% in Australia and above 90% in the USA by the year 2037 (Weeratunga and Somers, 2015; Wright et al., 2014). Further, the global market of CVs is expected to reach USD 131.9 billion by 2019 (Transparency Market Research, 2013). This has led to an influx of research and development activities in more countries (including Australia), with governments, car manufacturers (e.g. GM, Toyota), and high-tech companies (e.g. Google, Uber) investing heavily in CAV road testing. According to Bloomberg Philanthropies and the Aspen Institute [6], as of August 2019, 100 cities worldwide and more than 4 cities in Australia were hosting testing activities for CAVs. It is no exaggeration to say that CAVs research, development, and deployment is a new global race. Figure 1 represents CAVs interactions at critical roadway sections. At signalised intersections, CAVs can receive prior information about signal timings and adjust their dynamics. Similarly, CAVs can sense pedestrians when approaching a pedestrian crossing and then decelerate as required to allow safe crossing of pedestrians. As shown in Figure 2, CAVs can potentially interact with one another and safely pass through intersections without relying on traffic signals.

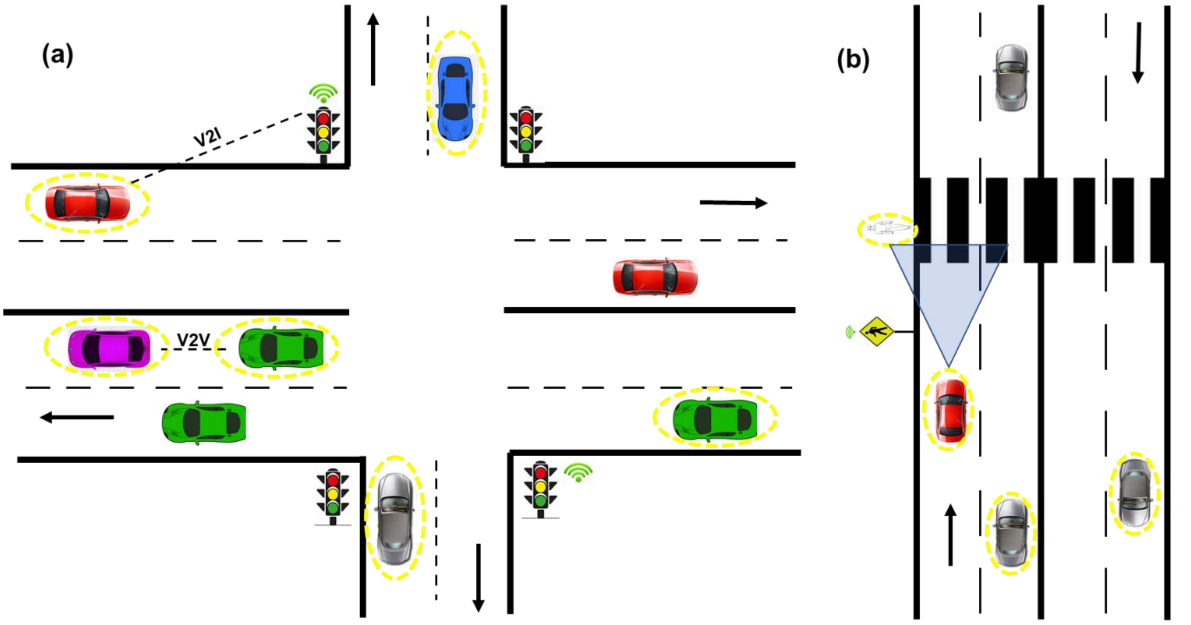

Figure 1. Traffic interactions of CAVs at critical roadway sections. (a) Signalised intersection; (b) Pedestrian crossing.

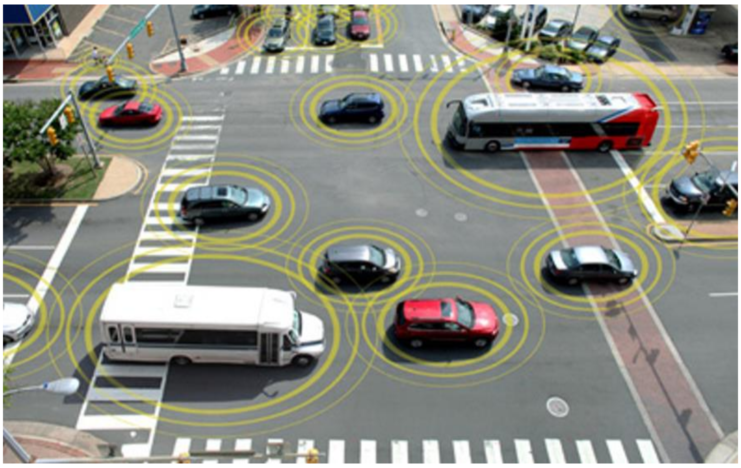

Figure 2. CAVs interact at intersection without traffic signals
(source: https://www.transportation.gov/)

Recent hiccups such as Google's driverless car crash (BBC, 2016), and the fatal crash of Tesla's autonomous car (The New York Times, 2016) raise severe and still unanswered questions regarding CAV's technical competency, its impact on surrounding traffic, and overall road safety. Other key issues associated with CAVs to be investigated before their wide-scale deployment in the real world are privacy, economic, security, and legal issues. This chapter explains various opportunities and challenges of CAVs. More specifically, this chapter answers the following questions: (i) How can CAVs assist in mitigating the ever-increasing traffic congestion? (ii) What are the expected road safety benefits of CAVs? (iii) How can CAVs assist in tackling the problem of vehicular pollution? (iv) How can CAVs increase societal productivity and improve overall mobility? (v) What are the economic, privacy, environmental, and legislative concerns associated with CAVs?

This chapter is structured as follows. Section 2 discusses various vehicle categories. Section 3 details CAVs benefits whereas Section 4 presents issues that may hinder CAVs' smooth deployment. Finally, the conclusion of this chapter is provided in Section 5.

2. Vehicle Categories

This section defines and discusses various vehicle categories.

Connected vehicles (CVs) are vehicles equipped to provide surrounding traffic information to drivers via vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-everything (V2X) communications. V2X communication includes transmission of information to vehicles, infrastructure, pedestrians, aftermarket devices, and any entity that may affect the CV's dynamics. The key advantages of CVs include enhancing traffic efficiency by alleviating traffic congestion, improving traffic safety, and reducing traffic emissions (Kim, 2015). The driver has full control of the longitudinal (i.e. car-following) and lateral (i.e. lane-changing) driving tasks, and the role of connectivity is only to assist the driver in decision-making by providing information such as position and speed of the lead vehicle, the gap with the lead vehicle, and an incident at the downstream,

V2V and V2I research began under the vehicle infrastructure integration initiative in the year 2003. However, its origin dates back to 1996 when General Motors introduced the first connected cars (Galler and Asher, 1995; Qi et al., 2009). These cars had an internal system that connected to an OnStar Advisor when airbags were deployed. The OnStar Advisor then relayed the transmitted information to emergency responders (Auto connected car news, 2014). The global race of mastering CVs technology has picked up the pace in the last 10 years. Some of the communication platforms available today for V2V and V2I communications are Dedicated Short Range Communications (DSRC), Wi-Fi, Worldwide Interoperability for Microwave

Access (WiMAX), Cellular Bluetooth, and 3G/4G/5G. The US Department of Transport has adopted 5.9 GHz DSRC as the primary platform for CVs safety applications. The authors note that 5.9 GHz DSRC is a secure, low latency (latency is a time delay measure between sending and receiving information), wireless mobile data communication technology. A more detailed discussion on DSRC is presented in Bettisworth et al. (2015).

Automated Vehicles (AVs; also termed as autonomous vehicles) are vehicles enabled to perform all the driving tasks in all the cases encountered with no human intervention required. Notably, this definition represents the highest level of automation (level 5). The Levels of automation as per Society of Automotive Engineers (SAE) (SAE, 2016) are discussed below. In the year 2016, National Highway Traffic Safety Administration (NHTSA) has also adopted the same levels of automation. Note that in this chapter, the terms "automated" and "autonomous" are used interchangeably.

Level 0 (No Automation): All the driving tasks are in drivers' hands. The system may issue warning messages but it is at drivers' discretion to comply or not.

Level 1 (Driver Assistance): The driver assistance system executes either steering or acceleration/deceleration. Human driver performs the rest of the driving tasks and monitors the driving environment.

Level 2 (Partial Automation): The driver assistance system executes both steering and acceleration/deceleration. Human driver performs the rest of the driving tasks and monitors the driving environment.

Level 3 (Conditional Automation): The automated driver assistance system executes all the driving tasks and monitors the environment. Human driver has to respond appropriately whenever the system requests the driver to take over.

Level 4 (High Automation): The automated driver assistance system executes all the driving tasks and monitors the environment even if the human driver does not respond appropriately to the system's request.

Level 3 and Level 4 are driving mode specific (a driving mode refers to a driving scenario such as high speed cruising, merging/diverging, low speed following, etc.). For instance, it is possible that an AV performing at level 4 automation will be capable of performing all the driving tasks as well as monitoring the driving environment in case of low speed following, high speed cruising, and merging/diverging. However, the driver has to perform the driving tasks in case of traffic jams where more tactical aspects of driving are involved.

Level 5 (Full Automation): The automated driver assistance system executes all the driving tasks in all the driving modes under all roadway and environmental conditions.

It is important to highlight that driving tasks performed by the automation only include the operational (steering, acceleration/deceleration, monitoring, etc.) and tactical (lane-change, responding to a sudden event, etc.) aspects of driving. Strategic aspect of driving tasks (e.g., origin-destination points) is not involved.

Connected and Automated Vehicles (CAVs) are automated vehicles with communication capability. This connectivity can be added at each of the five automation levels described above. However, CAVs in general refer to AVs operation at level 5 automation with communication capability. It is expected that adding communication to automation will make automated vehicles safer and more efficient.

3. Opportunities of CAVs

CAVs will have a profound impact on traffic depending on two major factors: (1) the level of autonomy available in the market; and (2) the penetration level in the traffic stream. This section focuses on CAVs with level 5 automated vehicles, and the impact of CAVs penetration level is discussed later.

3.1 Congestion reduction and overall improved mobility

Traffic congestion is characterised by slower speeds, the stop-and-go phenomenon, longer travel time, and longer vehicular queuing. Traffic congestion can be triggered by many factors such as insufficient road capacity, driver errors, inadequate mass transit options, inefficient traffic signals, and improper road design and planning. Where such congestion occurs, this not only increases the travel time to the desired destination but it also slows down the economy. Congestion is becoming an epidemic in large cities. Traffic congestion can cost approximately 0.5-3% of the GDP of developed economies and up to 5% of the GDP of developing economies (Cox and Hart, 2016). In Australia, the Bureau of Infrastructure, Transport and Regional Economics estimated in 2015 that congestion costs Australia $16.5 billion per annum, and that without major policy changes, the cost to the Australian economy would increase to $27.7 to

$37.3 billion annually by 2030 (BITRE, 2015). Other negative impacts of traffic congestion include fuel wastage, pollution due to increased emissions, wear and tear of vehicles, and other social issues such as road rage due to stressed and frustrated drivers.

Proponents of CAVs advocate its potential in assisting to mitigate traffic congestion by virtue of each CAV being able to automatically adjust its speed and spacing depending on the traffic flow condition at the upstream. Early evidence of CAVs' capability to withstand the negative effects of congestion are reported in the studies investigating cooperative adaptive cruise control (CACC) vehicles. These studies suggested that CACC vehicles could improve traffic flow stability, increase road capacity, avoid stop-and-go driving, and improve traffic flow efficiency (higher average flow and average speed) in general (Ge and Orosz, 2014; Milanés et al., 2014; Naus et al., 2010; Ngoduy, 2013; Ploeg et al., 2011; Shladover et al., 2012; van Arem et al., 2006). Recently, several studies have examined the capability of CAVs to mitigate traffic congestion using simulation-based approaches. For instance, Wang et al. (2016) proposed and implemented decentralised and distributed algorithms to model CAVs (longitudinal control only) and concluded that CAVs could remedy the capacity drop phenomenon and improve the stability of traffic flow upstream of the jam area. Moreover, Ye and Yamamoto (2018a and 2018b) demonstrated that higher market penetration of CAVs in the heterogeneous traffic flow of CAVs and traditional vehicles increases road capacity. Similar conclusions have been reported in other studies as well (Monteil et al., 2014; Rajamani and Shladover, 2001; Rios-Torres and Malikopoulos, 2017; Xie et al., 2017; Zhou et al., 2017).

3.2 Road safety improvement

Road traffic fatalities are an unacceptable consequence of transportation. Each day around 3700 lives are lost globally in road traffic crashes, and more than half of those are pedestrians, motorcyclists, and cyclists (WHO, 2018). Driver errors and inappropriate road infrastructure and system design are the main causes of crashes. Owing to limited perception, anticipation, and judgement capabilities, drivers are bound to make errors. In addition, impaired or distracted driving leads to driver errors. In all likelihood, driver errors are related to a high proportion of crashes. For example, in the US in 2013 driver errors were estimated to account for around 94% of all crashes (NHTSA, 2015). The safety benefits of CAVs are centred on the elimination of driver errors. These vehicles are equipped with Radar, LiDAR, cameras, and artificial intelligence technology to detect and track road objects. Unlike human drivers, these vehicles do not experience fatigue, distraction and other human factors which often lead to driver errors. Moreover, CAVs can adjust their driving behaviour based on the information received from surrounding vehicles and roadside units via V2V and V2I communication. With the fusion of all these technologies, CAVs can become error-free and thereby dramatically improve the safety performance of road traffic.

Based on the historical crash data, a few studies have attempted to predict the safety impact of CAVs. Fagnant and Kockelman (2015) suggested that a 90% reduction in crashes could potentially be achieved based on the number of crashes due to human error. Drawing parallels to the introduction of automation in aviation and rail, and subsequently its success in aviation and rail due to appropriate infrastructure, proper navigation, and efficient traffic management, Hayes (2017) conjectured that road crashes can also be reduced to 1% of the present situation. Papadoulis et al. (2019) modelled the longitudinal behaviour of CAVs and evaluated CAVs' safety benefits using the Surrogate Safety Assessment Model. They conjectured that estimated traffic conflicts are reduced by 12–47%, 50–80%, 82–92% and 90–94% for 25%, 50%, 75% and 100% CAVs penetration rates, respectively. Ye and Yamamoto (2019) modelled the heterogeneous flow of traditional vehicles and CAVs, and reported that traffic safety improves with the increase of the penetration rates of CAVs as indicated by higher TTC (time to collision) values and lower frequency of safety-critical situations.

3.3 Environment protection and energy saving

Transportation is one of the major contributors of air pollution through tailpipe emissions (volatile organic compounds (VOC), fine particulate matter ($PM_{2.5}$), carbon monoxide (CO), nitrogen oxides (NO_x), sulphur dioxide (SO_2), hydrocarbons (HC) and carbon dioxide (CO_2)), evaporative emissions, resuspension of road dust, and particles from wear and tear. As the third largest consumer of energy and the largest consumer of petroleum products, our transportation systems produce over 80% of air pollution in urban areas worldwide (UNESC, 2009). This has a severe consequence on public health because exposure to ambient air pollution increases morbidity and mortality, and is a leading contributor to the global disease burden (Cohen et al., 2017). In Australia, road transport is responsible for about 16% of total greenhouse gas emissions in Australia (Whitehead, 2015). Transport-related greenhouse gas pollution levels increased by 3.4% in the 12 months to December 2017 and since 1990, they have increased by 62.9%, a higher rate than any other sector (The Climate Council of Australia, 2018). Road transport is estimated to be responsible for up to 30% of particulate emissions (PM) in European cities and up to 50% of PM emissions in Organisation for Economic Co-operation and Development (OECD) countries – mostly due to diesel traffic (WHO, 2012).

CAVs have the potential to reduce vehicular pollution. Firstly, CAVs can remedy traffic congestion as described in Section 3.2, and this will directly reduce the harmful effects of traffic congestion on air quality. Secondly, CAVs can contribute to energy and fuel savings. Zohdy and Rakha (2016) developed a CACC control algorithm for intersection control and reported fuel savings of 33%, 45%, and 11% for a traffic signal, all-way-stop, and roundabout, respectively. Moreover, Kamalanathsharma and Rakha (2016) demonstrated that Eco-CACC could provide fuel savings within the vicinity of signalised intersections in the range of 5% to 30%. Other studies also reported significant fuel consumption savings with CACC and CAVs (Kamal et al., 2016; Qin Yanyan et al., 2018; Rios-Torres and Malikopoulos, 2017). Finally, CAVs can lessen traffic emission, which also leads to improvements in air quality because these technologies emit no ozone-forming precursors or particulate matter that can cause respiratory illnesses. Qin Yanyan et al. (2018) performed numerical simulations of the mixed traffic of traditional vehicles and CAVs (longitudinal control only), and reported a reduction of 16%, 22%, and 16% in CO, NO_x, and HC emissions respectively at only 10% penetration rate of CAVs as compared to no CAVs in the traffic stream. Moreover, the emission reduction increases with the increase of the penetration rate of CAVs. Liu et al. (2017) smoothened the driving cycles designed by the US Environmental Protection Agency to represent CAVs driving profiles and estimated traffic emissions by using Motor Vehicle Emission Simulator (popularly known as “MOVES”). They reported that the mean emission reductions that could be achieved by CAVs compared to traditional vehicles are 10.89%, 19.09%, 13.23%, 15.51%, and 6.55% for VOC, $PM_{2.5}$, CO, NO_x, and SO_2, respectively. Similar conclusions on the potential for CAVs to achieve lower emissions are reported in other studies (Lee and Park, 2012; Tu et al., 2019; Yang and Jin, 2014).

Meanwhile, CAVs can also lead to significant energy savings as automation allows vehicles to adjust their motions more precisely and optimize their trajectories in anticipation of upcoming events (Vahidi and Sciarretta, 2018). CAVs can also be designed to move in a coordinated and more efficient manner. Optimised control, anticipated driving and coordinated driving are some of the features of CAV’s that will increase energy efficiency. The harmonising effect of energy-efficient motion of these vehicles can lead to additional energy saving. Overall, research shows that CAV can contribute to 3-20% energy saving (Vahidi and Sciarretta, 2018).

3.4 Increased societal productivity

CAVs have several societal benefits. The three major societal benefits are detailed below. **Reduced travel cost.** Travel cost is calculated based on the effort required of a traveller (level of comfort, safety, etc.), travel time, and financial costs (Milakis et al., 2017). Travel cost is expected to decrease with the introduction of CAVs. Firstly, CAVs reduce congestion related delays that results in less travel time and thereby less travel cost. Secondly, the cost of the fuel component of the travel cost will be reduced thanks to CAVs. Lastly, the discomfort during travelling is also a cost to travellers, and a greater travel comfort is anticipated from CAVs because of enhanced efficiency and smoothness of traffic. All these can reduce driver stress and tedium and thereby reduce travel cost.

Enhanced accessibility. In general, accessibility has four components including land-use, transportation, temporal, and individual (Geurs and van Wee, 2004). The land-use component is a mix of opportunities at the destination (e.g., jobs, shopping mall, facilities for recreation), demand at the origin, and the interaction between origin and destination. The temporal component involves time available to people to participate in activities, and opportunities available at different times at different destinations. The individual component reflects the requirements of the individual, capabilities of individuals, and opportunities available for individuals. The transport component involves the transport mode availability to travel between origins and destinations, and the comfort, reliability and safety provided by available modes. With CAVs, the prospects of enhancement in accessibility are higher because CAVs could affect all the components of accessibility (Alessandrini et al., 2015; Milakis et al., 2017). The land use component will be affected since CAVs could push the development of new centres for opportunities, the enhancement of previous destinations, and trigger changes in land use, e.g., diminishing demand for on-street and off-street parking. CAVs could perform various activities without any human intervention and thus, overcoming the time dependence of activities, and thereby impacting the temporal component of accessibility. Furthermore, CAVs influence the individual component of accessibility e.g., elderly travellers, children, travellers without a driver licence, and travellers with a physical disability may travel to their desired destination by using CAVs. Lastly, travel cost is expected to be reduced as CAVs penetration increases, as explained in the previous section, which will impact the transport component of the accessibility.

Childress et al. (2015) reported that perceived accessibility was enhanced when investigating the households' accessibility patterns in the presence of CAVs based transportation system. A 20% average increase in vehicles miles travelled (VMT) was observed for households located in more remote areas. Thakur et al. (2016) studied the travel behaviour and residential location choices (determined by the accessibility to employment) of people in Melbourne, Australia.

They reported a 3% increase for the population in the far suburbs and a 4% decline in the inner suburbs in the year 2046. Kim et al. (2015) developed an activity-based model to examine the impact of automated vehicles on travel behaviour on the assumption that a 50% increase in road capacity is expected with the introduction of automated vehicles. They reported an increase in accessibility for the whole Atlanta region (a 4% increase in VMT). Likewise, Meyer et al. (2017) suggested there could be moderate accessibility gains in rural municipalities with an assumption that automated vehicles are available for children, elderly travellers, travellers without a driver licence.

Improved mobility. CAVs or shared CAVs are an attractive mobility option for travellers from different demographics especially for non-drivers, elderly travellers, travellers with physical disability, and those who do not have access to private transportation (Anderson et al., 2014; Fagnant and Kockelman, 2015; Krueger et al., 2016; Meyer et al., 2017). Higher travel time reliability, greater comfort, increased utility of in-vehicle time, inexpensive mobility on demand, and better last-mile connectivity are potential reasons for this affinity towards CAVs. Introduction of CAVs can also bring ample employment opportunities for travellers mentioned above since transportation will no longer be a barrier for employment. Harper et al. (2016) estimated how vehicles miles travelled could change with automated vehicles. Non-drivers and drivers with medical conditions could increase light-duty vehicle miles travelled by 9% and 2.6%, respectively.

3.5 Economic benefits

Davies (2018) observes that CAVs could potentially add 7 trillion dollars to the world economy and save thousands of lives over the next decades. Vehicle production and sales of CAVs have the potential to rise due to the increased VMT since CAVs offer improved mobility at a reduced cost. Zhao and Kockelman (2018) predicted an increase of 20% VMT across Austin, Texas after the introduction of CAVs.

Fagnant and Kockelman (2015) presented a comprehensive analysis of the economic benefits of CAVs, and found that at 10% market penetration rate of automated vehicles, total savings of USD 16.8 billion could potentially be realised due to congestion reduction and fuel saving. Separately, a saving of USD 5.5 billion was predicted to be realised from the reduced volume of crashes (Fagnant and Kockelman assumed a 50% reduction in crashes and injury rate). They reported overall economic benefits totalling USD 196 billion with 90% automated vehicles market penetration, which is consistent with the findings of Manyika et al. (2013).

4. Challenges of CAVs

4.1 Transition period

Despite universal optimism about the market penetration of CAVs in the near future, and the rapid upward trajectory of the technological maturity we are witnessing, research on the operation, control, and optimisation of mixed traffic flow is rather limited because the impact of CAVs on transport systems, while revolutionary, is also evolutionary. Consequently, for the foreseeable future, CAVs will need to co-exist with traditional vehicles (i.e., the present-day vehicles without communication capabilities and driver assistance) in a mixed traffic flow, as depicted in Figure 3.

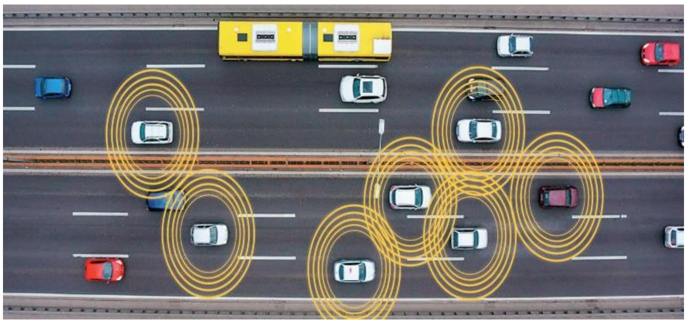

Figure 3. Traffic mixed with traditional vehicles and CAVs (source: https://www.sogeti.com/)

In the case of CAVs, the operational and tactical decisions are automated and human intervention, up to a certain level, will be required for strategic decisions such as deciding origin-destination points. In addition, as discussed previously, CAVs operation is error-free. On the other hand, in traditional vehicles, human drivers are in control of operational, tactical, and strategic decisions throughout the course of driving. However, due to limited perception, anticipation, and judgement capabilities, drivers are bound to make errors that can jeopardise traffic efficiency and, more importantly, traffic safety. The major differences in function allocation between human and hardware/software systems like automated vehicles are comprehensively addressed in the updated "Fitts List" as reproduced in Table 1 (Schoettle, 2017). Fitts' description of strengths and weaknesses across different aspects between human and hardware/software is valid for a comparison between human drivers and an automated system. As commented in Crist and Voege (2018), "one of the key premises of Fitts still holds today in light of driving functionality – tasks that humans are better at than automated driving systems should be performed by humans and tasks that automated driving systems are better at performing than humans should be performed by automated driving systems." The resultant mixed traffic flow of CAVs and traditional vehicles will have complex characteristics because of the differences in vehicular dynamics of CAVs and traditional vehicles, and understanding such characteristics of this mixed traffic will be critical in achieving the potential benefits of CAVs.

Table 1. Summary of differences between the human and the hardware/software system functions across different aspects as per the updated "Fitts List" (Schoettle, 2017).

Aspect	Human	Hardware/Software System
Speed	Relatively slow	Fast
Power output	Relatively weak, variable control	High power, smooth and accurate control
Consistency	Variable, fatigue plays a role, especially for highly repetitive and routine tasks	Highly consistent and repeatable, especially for tasks requiring constant vigilance
Information processing	Generally single channel	Multichannel, simultaneous operations
Memory	Best for recalling/understanding principles and strategies, with flexibility and creativity when needed, high long-term memory capacity	Best for precise, formal information recall, and for information requiring restricted access, high short-term memory capacity, ability to erase information after use
Reasoning	Inductive and handles ambiguity well, relatively easy to teach, slow but accurate results, with good error correction ability	Deductive and does not handle ambiguity well, potentially difficult or slow to program, fast and accurate results, with poor error correction ability
Sensing	Large, dynamic ranges for each sense, multifunction, able to apply judgement, especially to complex or ambiguous patterns	Superior at measuring or quantifying signals, poor pattern recognition (especially for complex and/or ambiguous patterns), able to detect stimuli beyond human sensing abilities (e.g., infrared)
Perception	Better at handling high variability or alternative interpretations, vulnerable to effects of signal noise or clutter	Worse at handling high variability or alternative interpretations, also vulnerable to effects of signal noise or clutter

Recently, several studies have focused on understanding and modelling the mixed traffic of CAVs and traditional vehicles (D. Chen et al., 2017; Z. Chen et al., 2017; Fernandes and Nunes, 2012; Ghiasi et al., 2017; Gong and Du, 2018; Jia et al., 2019; Jia and Ngoduy, 2016; Jiang et al., 2017; Rios-Torres and Malikopoulos, 2018; Ye and Yamamoto, 2018c; Zhao et al., 2018). These studies appear to converge on a conclusion that with the increase in the penetration rate of CAVs, the positive impacts of CAVs such as increased capacity, enhanced stability, reduced emissions, etc., become visible.

Due to the paucity of real data, the aforementioned studies assessed the dynamics of CAVs and the mixed traffic using simplified models and under strong assumptions. They also ignore critical factors e.g., human factors since they will play a major and a predominant role in governing the mixed traffic dynamics. Learning from the recent studies on CVs using driver simulator data can assist in understanding the complexity and challenges in modelling and assessing the mixed traffic flow of future vehicles and traditional vehicles (Ali et al., 2019, 2018; Sharma et al., 2019a, 2019b).

First, modelling of future vehicles such as CAVs should consider human factors that may impact its dynamics. For instance, Sharma et al. (2019a) reported that driver compliance is a critical human factor that impacts the behaviour and success of CVs (the advantages of CVs nullify if drivers do not comply). Consequently, they modelled the car-following behaviour of CVs by considering driver compliance. Ali et al. (2019) modelled the decision making behaviour of drivers during the mandatory lane changing by using a game theory approach in the connected environment. Sun et al. (2018) also incorporated human factors such as response time in the CV car-following model to realistically represent the behaviour of CVs when examining the stability of the CVs.

Second, considering the spatial arrangement/distribution of CAVs in the traffic stream can produce more realistic and reliable results. Sharma et al. (2019b) demonstrated the importance of the spatial arrangement of CVs in a platoon at a given penetration rate and its impact on the traffic flow efficiency and safety. Importantly, an inefficient arrangement of CVs will not enhance traffic flow efficiency and safety even where there is a high penetration rate of CVs. Finally, a realistic representation of a traditional vehicle is of utmost importance when modelling such mixed traffic. For example, traditional vehicle models should consider perception and estimation errors, multivehicle anticipation, and other human factors.

4.2 Economic Disruption and Issues

The advent of CAVs will disrupt several industries. In the US, the public transportation and taxi industries account for USD 66 billion and USD 20 billion in annual revenue, respectively in the USA. Ridesharing apps have already caused a 6.7% annual decrease in taxi service between 2011 and 2016, and decreases as large as 30% in Los Angeles and 65% in San Francisco, California. With the addition of CAVs to ridesharing services, a 50% decrease in taxi revenues would cause a shift of USD 10 billion in revenue toward ridesharing. This will signal a shift from private mode of transport to ridesharing, which has already started to ascend in major cities of the United States and other developed nations. If CAVs eventually become mainstream, they will have a strong economic impact, with a total effect potentially as much as USD 1.2 trillion annually or USD 3,800 per American per year (Clements & Kockelman, 2017).

The economy of manufacturing the tools to deploy CAVs successfully is complicated. Maps, radars and cameras are already in use in most of the vehicles. There is continuous progress in developing more futuristic versions of these tools to make CAVs better and safer. Moreover, there is a high use of LIDAR (Light Detection and Ranging) and machine learning required in driverless vehicles. LIDAR is used at the top of the vehicles to detect signals and laser beams. It requires a higher level of 3D mapping and HD-quality cameras. It is expensive to manufacture LIDAR, which are sophisticated and robust enough to not be affected by the present external environmental factors. This manufacturing cost, in turn, raises the prices of commercial CAVs and make them unaffordable for common people (Fagnant and Kockelman, 2015). Numerous start-ups and technological giants are investing millions of dollars into fixing all these problems (Davies, 2018).

Furthermore, CAVs are employing deep machine learning (ML) and artificial intelligence (AI) algorithms. Traditional vehicle manufacturers are investing billions of dollars into including artificial intelligence in their R&D departments, e.g., Ford has invested a billion dollars into its artificial intelligence unit Argo AI to build autonomous vehicles by 2021 (Biggs, 2017). Moreover, a change in the way industries operate is possible with employees expected to possess expertise in multiple fields. For instance, mechanical engineers need to constantly upgrade their skills or learn new skills in order to stay relevant as companies start to use more ML and AI in the designing of driverless vehicles. This changes the way the auto industry has functioned traditionally.

In addition, CAVs will affect jobs in the transportation sector, rendering jobs where workers are primarily responsible for driving a vehicle, such as a taxi, truck, bus; and jobs associated with driving such as traffic police officers, and driving instructors potentially irrelevant. CAVS can also profoundly impact vehicle service sector. For instance, the demand for low-skilled labour will likely decrease, while new services that require skilled labour such as for checking the electronics and software will likely emerge and flourish. Groshen et al. (2019) conducted a simulation-based study to understand the impact of autonomous vehicles on jobs and concluded that 1.3 to 2.3 million jobs would be lost over a 30-year time period. This study raised serious concerns regarding the imposition of this high cost on displaced workers. The study reported that hundreds of thousands of US workers would be displaced and each displaced worker will loose on average $80,000 in total. In developing countries like India, there have been a lot of hurdles faced by the companies trying to get CAV's on the road. A primary reason being the number of jobs it can negatively affect. The main concern of drivers losing their jobs due to CAVs has led to calls for ban on the testing of the CAVs (Dhabhar, 2018).

Another industry which will face big changes due to the advent of CAVs is the insurance industry. Safety improvements as a result of CAVs will require insurance agencies to adapt and possibly reconstruct their fundamental business models. Insurance companies sell policies to individual vehicle owners, and human drivers are liable for car crashes. Insurance agencies currently net $180 billion annually in the United States by insuring against automobile accidents and related medical costs (Clements and Kockelman, 2017). When there is a crash involving the CAVs, the automotive companies and the vehicles software providers will likely become the main liable parties since computers control CAVs. Klynveld Peat Marwick Goerdeler (KPMG) estimated that CAVs could shrink the insurance industry by 60% (Albright et al., 2015). This will change the landscape of the insurance industry, and will require novel legal frameworks to capture any potential liability of software and hardware manufacturers for any future crash

4.3 Privacy and Security Issues

For the proper functioning of CAVs, a huge amount of data will be collected and used, such as location, origin and destination, vehicle information, and trip information. Inevitably, some of the data will be private and sensitive. The huge amount of data generated from the interactions between users and CAVs is usually stored in the cloud, which is always under threat from cyber attackers. Further, the surveillance of GPS-based positioning and RADAR and LIDAR based detection raises a number of privacy concerns. For example, the collected GPS data can contain information about a user's home and office address, social and casual activities (Iqbal & Lim, 2010). The importance of cyber security to safeguard this highly personal, and oftentimes sensitive, cannot be overstated, and there is a strong likelihood that such datasets would be under constant threat from hackers. Recently, two hackers proved this was possible when they remotely took control of a Jeep Cherokee a few years ago (Law, 2019). However, limited research has been conducted to assess this privacy threat in real-life scenarios. To avoid the misuse of data, protocols and safeguards will need to be established so that the sensor data obtained from CAVs are used only for their intended purposes, which should remain as narrow as possible while still maintaining an idealised spectrum of functionality in CAVs.

A major threat to security with the rise of CAVs comes from the potential weaponizing of CAVs to conduct terrorism activities. In 2014, the FBI Strategic Issues Group prepared a report warning that autonomous cars could be used as lethal weapons since criminals may override their safety features (Harris, 2014). When the power of a vehicle is controlled by a single press of a remote switch, the scope of harm that it can cause rises massively. With an increase in radicalism and fanaticism, the ways to use the CAVs dangerously is multiplied. To cope up with the challenges related to CAVs' security risks, the legislature will need to consider how every single CAV should operate, which government agencies can handle any data obtained, and how to mitigate misuse of such data. This in turn may lead to more concerns with the privacy issues since data of every CAV could potentially be shared with agencies. Accordingly, there remains a tension between the need for access to secure the safety of the public and any privacy issue of a user (driver or passenger) within the CAV network. This requires any trade-off between security and privacy be dealt with judiciously.

4.4 Legislative Issues

There are also many important legal issues related to operating CAVs on public roads. Different jurisdictions (both at national and sub-national levels) may adopt differing regulatory frameworks regarding the testing, and deployment of automated vehicles. In the US, 21 states and the District of Columbia have passed automated vehicle legislation, and 6 states have executive orders passed (Hubbard, 2018). At the national level, the US National Highway Traffic Safety Administration (NHTSA) has published the Federal Automated Vehicles Policy in 2016 governing the use of CAVs. However, the policy provides guidance rather than imposes a statutory obligation on manufacturers, and sets forth a standard framework for levels of autonomy, vehicle performance, a model state policy, and current and future regulatory tools for the deployment of CAVs (Hubbard, 2018). In addition, each state in the USA has defined its own unique set of terms related to automated vehicles, and addressed various other legal issues including study request, licensing, registration, insurance, liability, operator requirements, infrastructure, vehicle testing and operation, commercial vehicle operation, and privacy. The consequent regulatory landscape around CAV technology is complex. Further, as CAV technology progresses and new terms related to automated vehicles come up, the legislation will continue to be updated and new statutory obligations may arise.

Several European countries have also introduced regulations for automated vehicles on public roads and require the issuance of autonomous testing permits. Germany passed a law in 2017 allowing companies to test self-driving cars on public roads, while in The Netherlands, the Council of Ministers first approved driverless vehicle road testing in 2015. Likewise, the UK has passed a bill to draw up the liability and insurance policies related to autonomous vehicles.

In Asia, similar statutory frameworks around the testing of autonomous vehicles are being developed. Shanghai, China recently issued its first self-driving licenses in 2018. In South Korea, the K-city project is the largest town model ever built for self-driving car experimentation. In India, there is testing of CAVs, however, concerns regarding job loss have led to calls on banning the CAVs (Dhabhar, 2018).

4.5 Ethical Issues

CAV technology promises to reduce road crashes by eliminating driver errors. Consider a scenario where a CAV is approaching a pedestrian crossing. Suddenly, the CAV experiences a mechanical failure and is unable to stop. If the CAV continues on this path, it will crash into a bunch of pedestrians crossing the street or if the CAV swerves hitting one bystander thereby killing him/her and saving the pedestrians or if the CAV swerves and crashes into a wall thereby killing the passengers to save the pedestrians. What should the CAV do and who decides the course of action? This scenario captures the trolley problem that represents a classic clash between utilitarianism and deontological ethics (Thomson, 1985). Once CAVs start travelling on public roads, these kinds of scenarios will certainly occur. Similar scenarios with less severe consequences are also quite possible where CAVs must carry out complex calculations to decide the course of action involving a trade-off (e.g., increasing the risk to passengers versus hitting pedestrians).

The “Moral Machine Experiment” was the largest-ever survey on machine ethics, designed to explore the moral dilemmas faced by automated vehicles. Responses were obtained from 233 countries and territories, of which 130 countries had at least 100 respondents (Awad et al., 2018). In one of the scenarios, respondents had to choose between the two possible outcomes of an autonomous vehicle brake failure. If the autonomous vehicle stayed on course, it would result in the death of three elderly pedestrians who are crossing on a ‘do not cross’ signal, whereas if the vehicle swerved, this would result in the death of three passengers. This choice is primarily an ethical dilemma within itself. There will be no black and white answer, and the choice will differ from person to person, based on a variety of factors, including culture and individual values and beliefs. With the removal of the human driver this decision will not be made by the occupant of the vehicle but the vehicle itself. In their recent paper published in Nature, Awad et al. (2018) stated that “Never in the history of humanity have we allowed a machine to autonomously decide who should live and who should die, in a fraction of a second, without real-time supervision. We are going to cross that bridge any time now.” This underscores the importance and urgency of having a thoroughly-designed ethical system in place to ensure that these decisions are ethically justifiable.

German Ethics Commission on Automated and Connected Driving proposed ethics rules in 2017 (Luetge, 2017). To the best of the authors’ knowledge, this is the only attempt to provide official guidelines for the ethical choices of autonomous vehicles. Two important guidelines are presented below.

> **German Ethical Guideline 7** “*in hazardous situations that prove to be unavoidable, despite all technological precautions being taken, the protection of human life enjoys top priority in a balancing of legally protected interests. Thus, within the constraints of what is technologically feasible, the systems must be programmed to accept damage to animals or property in a conflict if this means that personal injury can be prevented*”

> **German Ethical Guideline 9** “*In the event of unavoidable accident situations, any distinction based on personal features (age, gender, physical, or mental constitution) is strictly prohibited. It is also prohibited to offset victims against one another. General programming to reduce the number of personal injuries may be justifiable. Those parties involved in the generation of mobility risks must not sacrifice non-involved parties*”

Guideline 7 unambiguously states that avoiding injury to humans takes priority over avoiding damage to property or animals, while guideline 9 states that collision programming should be independent of any personal feature bias. Importantly, guideline 9 does not take an unambiguous stand on the collision programming of automated vehicles in scenarios when there is a trade-off between the number of lives that the vehicle can save. Justifiably, this guideline was not accepted unanimously by the committee's members (Luetge, 2017). Nyholm and Smids (2016) reported the ethical issues when deciding how to program automated vehicle to respond to unavoidable accident scenarios. Their study suggests that the ethical issues relate to (i) decision-making faced by groups and/or multiple stakeholders; (ii) risk and/or decisions uncertainty; (iii) morally loaded (situations involving significant ethical dilemmas) prospective decision-making and/or contingency planning; (iv) both backward-looking[1] and forward-looking[2] moral and legal responsibility; and (v) open-ended ethical reasoning taking wide ranges of considerations into account.

Today, proponents of driverless vehicles face additional critical and unanswered ethical questions other than the question raised above (Bogle, 2018). First, which risks are worth taking? Second, is the CAV making a choice, or are we? Third, is there a moral code we can all agree on? Fourth, should we choose our own CAV's moral code? Last, can we ever trust CAVs? These questions must be answered before CAVs can be accepted as a mainstream mobility tool.

5. Conclusion

Experts predict that connected and/or automated vehicles (CAV) will fundamentally transform how humans travel and revolutionise the automobile-related industry through the creation of a safe, efficient, and effective interoperable wireless communication network. Globally, governments are beginning to appreciate the importance of this technological revolution to their national interest (economy and security in particular). This has seen nations join the race to be world leaders in connected and automated vehicle research and development. As a result, CAV research and development has been rapidly growing over the past 10 years, with CAV technology improving rapidly, and a number of commercially-realised features have entered the market. However, the adoption of CAV technology remains highly complex. The main

[1] Backward-looking responsibility is the responsibility that people can have for something that has occurred in the past either because of them or something they allowed to happen.
[2] Forward-looking responsibility is the responsibility that people can have to prevent something to happen in the near or distant future.

opportunities and challenges related to the deployment of CAVs have been comprehensively reviewed in this chapter.

From a road transport perspective, CAV technology promises to reduce traffic congestion, increase road capacity, enhance traffic stability, reduce vehicle emissions and its harmful effect on air quality, and improve fuel economy. From a societal public policy perspective, CAVs have the potential to improve mobility for the elderly, the young, and people with a physical disability. Additionally, with appropriate planning and implementation, CAVs can enhance the overall accessibility of a city and reduce travel cost.

At the same time, the path to a full implementation or a high market penetration of CAVs faces many critical challenges. For example, the initial cost of CAVs will be high due to its current low market penetration. Adoption of the technology can also lead to job loss and interrupt insurance industries. The sensorised data associated with CAVs and the collection, transmission, storage and subsequent use of such data can lead to serious privacy and security issues, underscoring the numerous complicated regulatory and ethical issues still at play. Currently, limited ethical guidelines and regulatory frameworks governing CAVs are available for supporting the appropriate adoption of CAVs.

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