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Investigating the state of connected and autonomous vehicles: a literature Review

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Abstract

Connected and autonomous vehicles (CAVs) are expected to be deployed in the near future, however it is still not clear whether the technology will provide more benefits than it will present drawbacks. This study aims to collate the research already completed in this domain and highlight an area of knowledge which is currently lacking sufficient investigation. The review shows that there is a wide range of topics and sub-topics covered in this area. We focused mainly on three key sub-topics that had fewest studies: adaptive tolling systems, autonomous parking facilities and predicting adoption over time. Past work on adaptive tolling has predominantly modelled situations where the traffic condition is uniform, whereas the impact of dynamic traffic and unexpected events or incidents has not yet been considered. Studies on autonomous parking facilities need to focus more on closely simulating normal operating conditions, such as having multiple operational vehicles, multiple parking spaces and a mix of CAVs and traditional vehicles. Although the positives of CAVs have been the predominant focus of discussion, the technology does present a number of uncertainties that make the full picture of its implementation and effects on its environments incomplete. An assumption made in many studies is that the market penetration of CAVs is 100%, however this will not be the case for some period of time. Therefore, studies need to consider the rate at which CAVs are adopted, which can be influenced by a number of factors.

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Keywords: driverless car; human factors; adoption rate; automation; traffic

1. Introduction

The research and development of fully connected and autonomous vehicles, or CAVs, which are able to navigate roads without a human driver and connect and interact with other vehicles and their environments has increased rapidly in recent times. It is anticipated that the technology will be made available to consumers in the very near future, with some predicting that fully autonomous vehicles could be on the market as soon as 2025 (Nieuwenhuijsen et al., 2018).

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However, there are still many hurdles in the way of their deployment. Despite discussion focusing on their benefits they could prove to be incompatible with or even detrimental to their environments in some ways.

The deployment of connected and autonomous vehicles is expected to provide numerous opportunities to improve road environments and society. Through the application of cooperative adaptive cruise control (CACC), it is possible to improve the efficiency and stability of traffic flow on a highway (Arem et al., 2006). Additionally, research has been done on other CAV-related concepts such as variable speed limits (VSL), and how these technologies could help prevent or remove traffic bottlenecks (Han et al., 2017). Simulations of first-come-first-serve (FCFS) intersections show that the resultant intersection delay compared to that of traditional signalling is significantly lower (Fajardo et al., 2011). As well as demonstrating the benefits to passenger vehicles, studies have validated the potential for connected vehicle environments to enable more efficient signal prioritization for public transport vehicles without having significant adverse impacts on other road users (Hu et al., 2014).

Along with the improvements that CAV technologies could bring to road networks, there are benefits that will be brought to society in general. As emission reduction targets are continually increased globally, real world experiments across multiple European cities have been conducted to show how vehicle to vehicle and other infrastructure (V2X) technologies can improve fuel consumption and thus help further reduce vehicle pollution (Edwards et al., 2017). Safety is another key concern when it comes to developments in vehicle technology, and the potential improvements in the collision avoidance and hazard warning capabilities of passenger vehicles in CAV environments are being investigated in depth (Bila et al., 2017).

Research has already been undertaken on various aspects and applications of the technology, however the extent to which each topic has been covered varies and it is likely that some areas of research have significant gaps in knowledge. Therefore, the capabilities and impacts of these vehicles which have been researched in relation to higher levels of autonomy should be compiled and analyzed, and the areas of research where there may be a lack of knowledge should be identified and investigated further. It is also important to explore how the technology may be better or less suited to a particular location of interest, rather than only looking at the general global impacts or its benefits within other geographical settings with different characteristics.

CAVs have the potential to provide many benefits to not just automotive systems, but to the urban landscape and society as a whole. It is expected that their introduction will reduce congestion, make roads safer and also allow time spent inside a vehicle to be used in new ways (Chen et al., 2017). With the constantly increasing research being done on these technologies, and arguments both for and against their adoption, it is vital to assess the positive and negative impacts of such vehicles, and highlight and explore areas of uncertainty, so that their inevitable deployment is as smooth and advantageous as possible.

This assessment can be achieved through the analysis of existing literature on interest areas related to CAVs to determine where further research is required, and the subsequent investigation of a topic related to the technology that is most significantly lacking research in an attempt to fill gaps in knowledge and help make an effective judgment on all of the benefits and drawbacks of the technology. Therefore, the overall aim of this study is to conduct a state-of-art review on the opportunities and uncertainties presented by the adoption and deployment of CAVs. Specifically, we aim to examine which of these opportunities and uncertainties have already been sufficiently researched and analyzed for their potential benefits or drawbacks, and which key area of research into CAVs is significantly lacking investigation and critical analysis.

The structure of the paper is as follows. The next section briefly explains the methodology adopted for the review. We then present the key findings. Finally, we present the discussions and conclusions.

2. Methodology

In order to obtain a clearer picture of whether the introduction of CAVs will positively or negatively impact on the environment and society, a sample of 100 journal articles was sourced from electronic databases including ISI Web of Science, Scopus and Google Scholar in order to create an initial literature overview and identify the areas lacking knowledge. The articles were predominantly taken from the following leading journals in this field: Transportation Research Part A, B and C, Transportation Research Record and IEEE Transactions on Intelligent Transport Systems. The Boolean search terms used to find the journal articles were “connected vehicle”, “autonomous vehicle”, “driverless car/vehicle” and “automated vehicle”. In Fig. 1 below, the number of journal articles published per year is depicted for the sample taken. From this, the rapid increase of research and study into CAVs in recent years is clear. The low number of articles from 2018 is due to this sample having been taken in mid-February of that year.

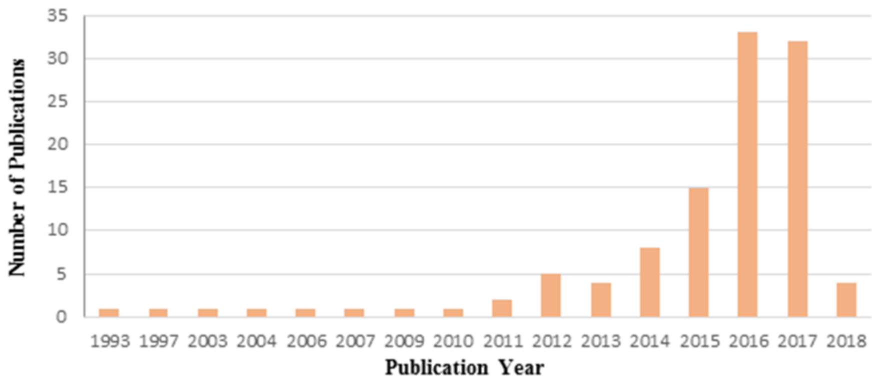

Fig.1. Number of journal articles from literature sample by year of publication

The initial relevance of the journal articles was determined primarily on their title, as well as a brief review of their content and key theme or topic. The predominant themes or topics of the 100 articles were then identified and a tree of general topics and sub-topics related to the opportunities and uncertainties surrounding CAVs was created. These topics, which are categorised as opportunities or uncertainties, are shown in Figure 2. Under opportunities, the focus is on ‘Improvements to road networks’, ‘Improvements to society’, and ‘New services + systems’ to users; while under uncertainties, the emphasis is on ‘Adoption rate’ and ‘Effectiveness with mixed vehicle environment’. The key topic areas defined by this tree are:

- improvements to road networks: where controlling vehicle speeds or traffic signaling at intersection through the use of CAVs will improve traffic flow and manage congestion
- improvements to society: other significant social and environmental benefits that could emerge as a result of CAV implementation
- new services + systems: how the urban landscape may change with CAV adoption
- adoption rate: how quickly CAVs will replace traditional vehicles, and the factors which will influence their adoption
- effectiveness with mixed vehicle environment: whether CAVs will have a positive impact on roads and traffic if the market penetration is low and is mixed with traditional vehicles.

Under each main topic (excluding effectiveness with mixed vehicle environment topic), there are sub-topics as shown in Fig. 2. The number of articles found for each topic and sub-topic is shown in Figures 3 and 4, respectively. Please note that ‘improvements to road networks’ accounts for 34 papers, making it the second highest key topic covered by the tree. However, being such a diverse topic area, ‘controlling vehicle speeds’ and ‘traffic signaling’ were identified as two further key themes under ‘improvements to road networks’, and therefore sub-topics for this category are based on those two themes. From Fig. 3 it is seen that the improvements which CAVs could bring to society are by far the most discussed area in existing research, with this topic having more articles than the next two topics combined (Adoption rate and New services + systems). The significant variation in research into the different sub-topics covered by past studies is depicted by Fig. 4, with the most investigated topic of ‘emissions reductions’ having 24 articles, whilst the least covered area of ‘prediction adoption over time’ is represented by only three of the 100 journals in the literature sample. Please note that several studies covered different topics or sub-topics in their study and therefore the number of articles by topic or sub-topic as shown in Fig. 3 and 4 would exceed 100 due to the overlapping of different topics or sub-topics.

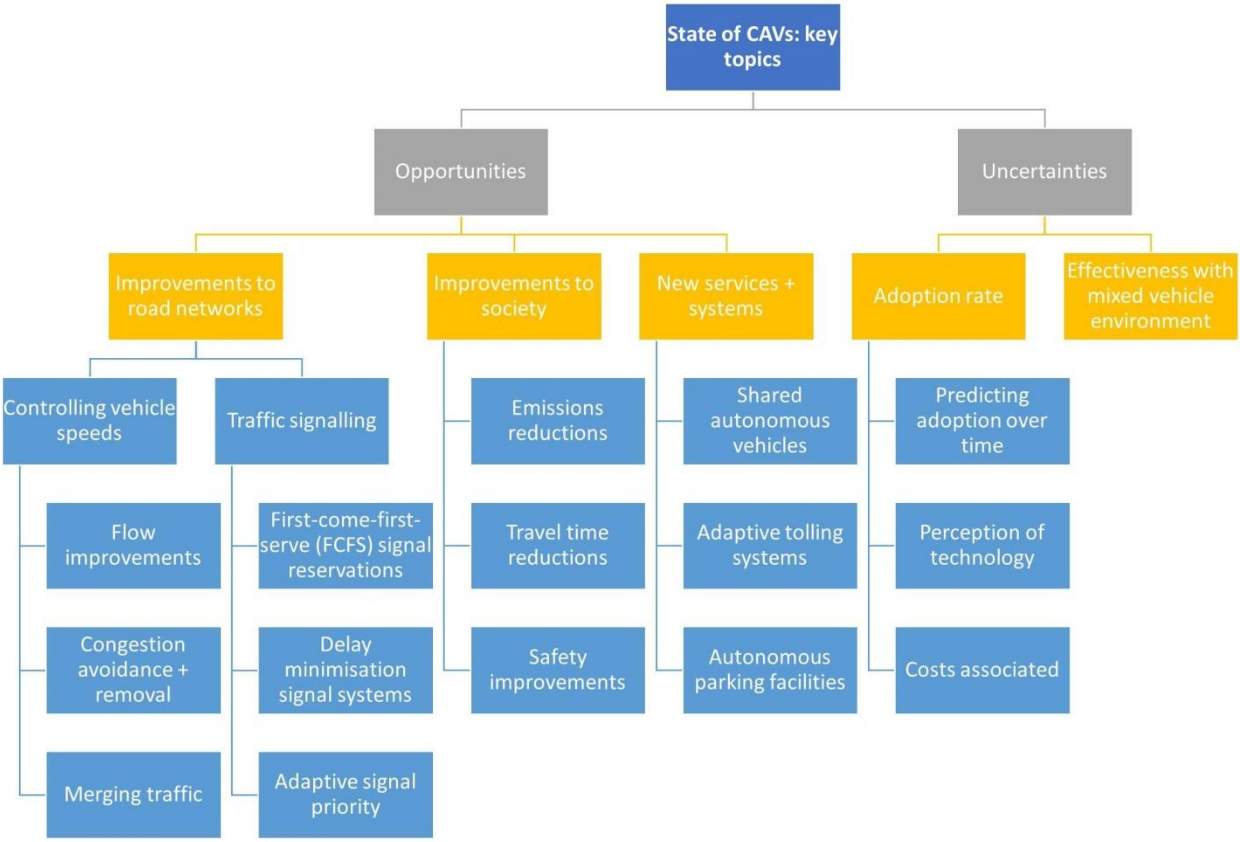

Fig.2. Topic and sub-topic tree of CAVs opportunities and uncertainties

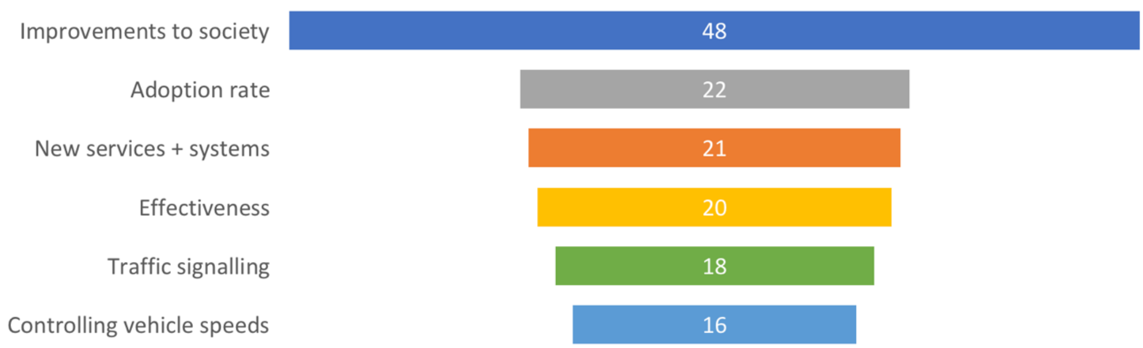

Fig.3. Number of journal articles from literature sample by topic

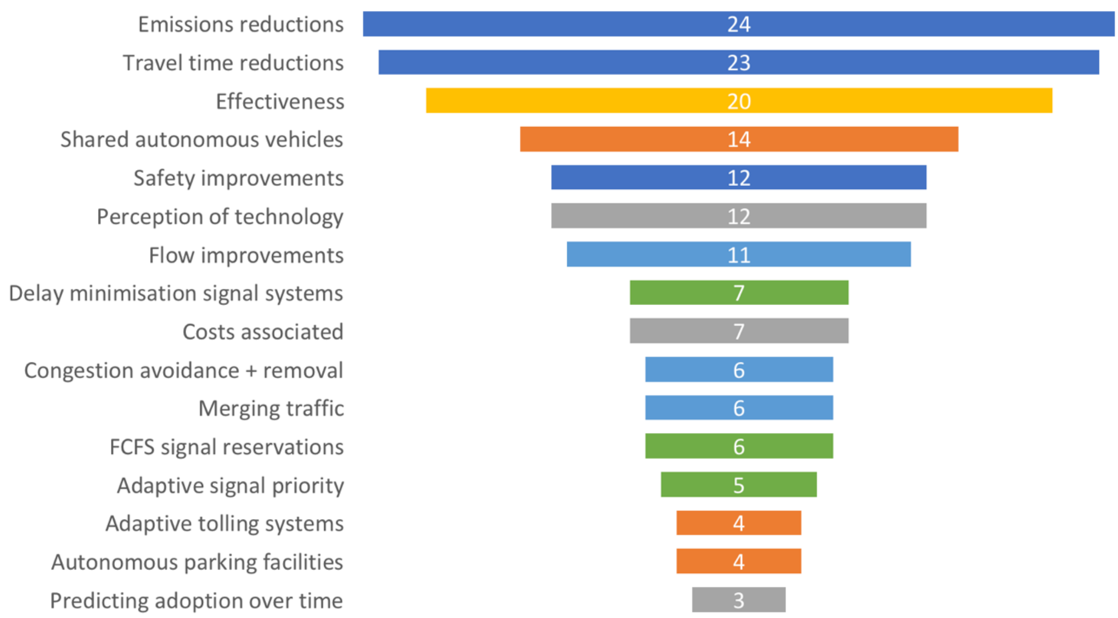

Fig.4. Number of journal articles from literature sample by sub-topic

Considering the wide range of topics and sub-topics in this area, as well as the aim of the study to highlight an area of knowledge that is currently lacking sufficient investigation, we restricted ourselves to the three sub-topics from the sample (addressing opportunities and uncertainties) with the lowest number of journal articles, which require further research. These sub-topics (and their corresponding topics) were:

1. Adaptive tolling systems (ATC) (Opportunities: New services + systems)
2. Autonomous parking facilities (APF) (Opportunities: New services + systems)
3. Predicting adoption over time (PAT) (Uncertainties: Adoption rate)

These three sub-topics each had less than five articles in the sample that covered the issue, and collectively represented less than seven per cent of the sub-topic coverage of the entire sample. This demonstrates the need for further exploration of these sub-topics in particular. Therefore, more detailed search terms using Boolean operators were used. Furthermore, resources other than journal articles (including conference papers and reports) were also considered at this stage. This updated search resulted in a total of 27 resources covering the three sub-topics that included 11 resources for adaptive tolling systems, 9 for autonomous parking facilities and only 7 for predicting adoption over time. In the next section we present some key findings from the detailed literature review of these three sub-topics.

3. Key Findings

As described in section 2, the key themes in each article from the sample taken were classified as either an opportunity (‘Improvements to road networks’, ‘Improvements to society’, and ‘New services + systems’) or an uncertainty (‘Adoption rate’ and ‘Effectiveness with mixed vehicle environment’). Most topics were further broken down into sub-topics that described specific ways in which CAVs were viewed as positive or negative by the given literature resource.

Under the theme of ‘Improvements to road networks’, the sub-topics of ‘Flow improvements’, ‘Congestion avoidance + removal’ and ‘Merging traffic’ were identified. With regards to ‘Flow improvements’, it was found that

Cooperative Adaptive Cruise Control (CACC) could have the ability to double or triple the flow rate of vehicle traffic by simply reducing vehicle headway (Lioris et al., 2017). Papers found in the 'Congestion avoidance + removal' category proposed various solutions that incorporated CAV technology to reduce or eliminate congestion, such as dynamically reversing a lane of traffic on a road depending on the predominant direction of traffic at a given time (Levin and Boyles, 2016). And a number of studies have been completed that use simulations to investigate how road traffic could be merged more effectively and efficiently through the use of CAVs under a variety of different scenarios, with some studies predicting potential improvements in merging flow of anywhere between 3 and 61 percent (Letter and Elefteriadou, 2017, Guériau et al., 2016).

'Traffic signalling' was the other aspect of 'Improvements to road networks' that was highlighted, and it comprises of 'First-come-first-serve (FCFS) signal reservations', 'Delay minimization signal systems' and 'Adaptive signal priority'. FCFS based intersections, which prioritise vehicles that arrive earlier at an intersection through the use of CAV technology, could reduce delays at intersections in comparison to traditional signaling (Fajardo et al., 2011, Levin et al., 2016). Other types of unconventional signaling methods have been investigated that aim to further reduce the amount of total delays at intersections without giving bias to those that have arrived earlier (Ilgin Guler et al., 2014, Lee and Park, 2012). The ability to exploit CAV technology to adapt signals to varying traffic conditions and for priority vehicles (such as public buses) has also been explored, with results showing potential benefits to impacted road networks (Hu et al., 2016, Feng et al., 2016).

'Improvements to society' were sorted under three categories: 'Emissions reductions', 'Travel time reductions' and 'Safety improvements'. The impact of CAVs on emissions levels was the sub-topic most covered by past studies, with many predicting significant reductions in fuel consumption after the adoption of CAVs. Based on factors including market penetration and the amount of traffic preview information available to vehicles, the level of savings were quantified as being anywhere between 5 and 33 percent (Han et al., 2017, Manzie et al., 2007). A significant number of journals have also investigated the impact of CAVs on the time spent in vehicles, with experimental results showing that, depending on the technique implemented, their introduction could reduce travel times by up to 33% (Lee and Park, 2012, Mostafizi et al., 2017). CAVs are also expected to make road networks safer, with the technology's ability to reduce the risk of collisions being highlighted by many papers as being a key advantage of their introduction (Han et al., 2017, Chakravarthy et al., 2009).

Two of the sub-topics under 'New services + systems', 'Adaptive tolling systems' and 'Autonomous parking facilities', were analysed further as part of this study and the key findings of these areas are presented later in this section. With regards to the remaining sub-topic of 'Shared autonomous vehicles', the introduction of CAVs that are not privately owned and the impact that they could have on roads and vehicle use was investigated by multiple studies. Key conclusions of these studies were that each shared autonomous vehicle, or SAV, on the road could replace up to 11 privately owned vehicles, but may increase total vehicle distances covered by 10% due to journeys without occupants (Chen et al., 2016, Fagnant and Kockelman, 2014).

'Predicting adoption over time', the sub-topic of 'Adoption rate' that was also investigated deeper in this paper, was accompanied in this topic by 'Perception of technology' and 'Costs associated'. Studies under the category of 'Perception of technology' found that concerns about safety, privacy and the effectiveness of the technology will dictate their actual adoption rate (Fagnant and Kockelman, 2015, Fries et al., 2012). The required financial investment for CAVs has also been explored due to its uncertainty. Past studies discuss whether the technology would be affordable for private ownership or more suitable for shared use, and estimate the price that the population would be willing to pay for various levels of vehicle automation based on survey data and how this will affect the rate of CAV uptake (Daziano et al., 2017, Wadud, 2017).

The other topic of uncertainty covered by the literature sample is 'Effectiveness with mixed vehicle environment', which was not broken down into sub-topics. The main findings of the existing literature are mostly based on the impact of a higher market penetration on the benefits obtained, as well as how beneficial the introduction of CAVs will be with a low penetration level. One such study found that fuel consumption and pollution could be reduced by 28 and up to 60%, respectively, with only ten percent of vehicles being CAVs(Bose and Ioannou, 2003). However most studies highlighted the importance of a high penetration of CAVs, claiming increases in roadway capacity of 33% when the level of penetration increases from 50% to 100% and reductions in fuel consumption of up to 58% and in emissions of up to 33% with a saturation level of 60% (Jiang et al., 2017, Chang and Lai, 1997).

Following the analysis of the initial sample of literature, an in-depth literature review was conducted for the three sub-topics: Adaptive tolling systems (ATC), Autonomous parking facilities (APF) and Predicting adoption over time (PAT). The main information taken from this review is summarised in Table 1 (found at the end of the Discussions and conclusions section). The table shows the type of resource found; the relevant sub-topic; whether it has a predominantly positive (+ve), neutral or negative (-ve) opinion of CAVs; and some of the key findings. In addition, as noted in the previous section, the sub-topic 'Predicting adoption over time' had the lowest number (7) of relevant resources. We further considered additional resources that focussed on adoption of technology other than CAVs. We found that methods focussed on the adoption of electric vehicles (EV) or plug-in-hybrid electric vehicles (PHEV) could be applicable to predict the adoption of CAVs. Hence, in Table 2, along with the resources on predicting adoption over time for CAVs, we have also added resources on adoption of electric vehicles (EV) or plug-in-hybrid electric vehicles (PHEV). Table 2 shows information on the influencing variables that need to be acquired in order to predict the rate at which CAVs will be adopted over time.

As can be seen in Table 1, within the defined sub-topic area of 'Adaptive tolling systems', modelling and simulated experiments were predominantly used to investigate whether the implementation of dynamically varying tolls to manage traffic flow and road utilisation would have a positive or negative impact, both physically and socially, on road networks and drivers. Many sources assert that such systems would be able to reduce travel times and maximise capacity utilisation (Basar and Cetin, 2017, Böhm and Frötscher, Sharon et al., 2016, Zhu and Ukkusuri Satish, 2014), although some note that those models focus on maximising operator revenues rather than benefits to vehicles (Cetin et al., 2015, Collins et al., 2015).

Observations from Table 1 reveals that 'Autonomous parking facilities' research is centred on determining how the introduction of CAVs could change the design of existing parking spaces as well as urban environments in general, and how traditional parking behaviours and manoeuvres can be altered to be more efficient and convenient. Studies have generally found that the uptake of CAVs will mean that vehicles can be parked further away from destinations than at present, as passengers can disembark the vehicle before it is parked (Klemm et al., 2016, Litman, 2017). Furthermore, reconfiguring existing parking facilities can drastically reduce space requirements given that drivers do not need to be present to move one vehicle out of another vehicle's way, and by allowing traditionally unacceptable manoeuvres such as double parking (Alessandrini et al., 2015, Estepa et al., 2017, Ferreira et al., 2014, Nourinejad et al., 2018).

For the sub-topic 'Predicting adoption over time', a mixture of surveys and modelling was used to address questions related to how quickly CAVs will be adopted, with the various dependent factors shown in Table 2. Initial cost and reduction in cost over time were identified as key influences in multiple studies, and it is seen that the rate of adoption of CAVs is increased when the price of such vehicles decreases sooner (Bansal and Kockelman, 2017, Lavasani et al., 2016). Perception of the effectiveness of the technology is another important factor, as well as willingness to pay for full automation, and government and authority regulation (Clark et al., 2016, Menon, 2015, Solbraa Bay, 2016). The specific demographics of different locations will also dictate how quickly CAVs are adopted, with younger and dense urban populations more likely to adopt the technology quicker (Lavieri et al., 2017). The influencing factors for adoption of CAVs as identified in Table 2 are:

- Cost: the purchase price of CAVs over time
- Demographic: the geographical and social factors behind a population
- External environment: the road network and physical environment, and their preparedness for CAVs
- Market size: the total number of vehicles, both CAVs and traditional vehicles
- Perception/acceptance: the population's opinion or view of CAVs
- Regulations: legislation enforced on a given market to mandate the ownership or sale of CAVs and the development of the required infrastructure
- Willingness to pay (WTP): related to cost, whether the population believes that the associated benefits of purchasing CAVs are worth the financial cost

4. Discussions and conclusions

Existing research on the benefits and drawbacks of CAVs has been explored, summarized and analyzed in this paper. The wide range of topics and sub-topics covered in this area prompted us to focus on three key sub-topics that had fewest studies: adaptive tolling systems, autonomous parking facilities and predicting adoption over time.

Multiple areas related to adaptive tolling systems have been highlighted as requiring deeper investigation in future studies. Past work has predominantly modelled situations where the traffic condition is uniform, whereas the impact of dynamic traffic and unexpected events or incidents has not yet been considered. As it would be somewhat unrealistic to impose tolls on all routes immediately, investigating which routes to toll in a designated area is also important. Consideration of other "real-world" conditions such as the modelling of multi-lane highways, merges and intersections, and mixed vehicle environments including buses and trucks rather than only passenger vehicles, will also be important in analysing the viability of such systems. And considering that in reality not all vehicles will respond to tolls in a predictable manner, studying the actual behaviour using surveys will be crucial in obtaining realistic insights.

In terms of the further work required for autonomous parking facilities, as the vast majority of the existing work has simply proposed and designed systems or facilities, future studies should be focused on exploring different variations of these proposals and analysing which system produces the best outcomes, as well as simulations and modelling of these designs. The various proposals will need to be tested under dynamic conditions and ultimately real-life experiments of these facilities must be conducted. For those studies that have already involved physical testing, further experiments that more closely simulate normal operating conditions, such as having multiple operational vehicles, multiple parking spaces and a mix of CAVs and traditional vehicles, will be the next stage of research.

Given that CAVs adoption possesses the characteristics of being dynamic, complex and uncertain, tools such as system dynamics (SD) have been suggested in the literature to investigate the adoption rate of connected and autonomous vehicles (Nieuwenhuijsen et al., 2018). System dynamics modelling is concerned with the study of dynamically complex mathematical systems and is commonly used to solve dynamic and non-linear problems not only for physical situations but also those involving social psychology and economics (Sterman, 2000). The maximum rate of adoption which is reached is dependent on the system variables and feedback loops built into the model (Sterman, 2000). Whilst the tool like SD is available, researchers are calling for data on the system variables (e.g., market size, external environment, Table 2) across different geographic regions and cultures.

It is expected that new services and systems will result from the deployment of CAVs, which will be advantageous to society and the environment. Simulations of shared autonomous vehicle (SAV) fleets at even a low level of market penetration have suggested that such systems are capable of significantly reducing the amount of private vehicles required to transport people around a city (Fagnant et al., 2015). Since such vehicles will not require humans to be present, parking facilities can be relocated to less built-up areas and redesigned to take up less space (Nourinejad et al., 2018).

Although the positives of CAVs have been the predominant focus of discussion, the technology does present a number of uncertainties that make the full picture of its implementation and effects on its environments incomplete. An assumption made in many studies is that the market penetration of CAVs is 100%, however this will not be the case for some period of time. Therefore, studies need to consider the rate at which CAVs are adopted, which can be influenced by a number of factors. The way in which the public perceives the technology will dictate the rate at which they replace conventional vehicles, and surveys have already been conducted on public opinions and attitudes towards CAVs in specific cities (Bansal et al., 2016). Cost is the other important factor behind the acceptance of such vehicles, and consumer willingness to spend more for partially and fully autonomous vehicles has also been researched and quantified so that their economic viability can be explored (Daziano et al., 2017).

The actual effectiveness of CAVs is also rather uncertain. Because a network of mixed autonomous and conventional vehicles for some period of time is inevitable, how such a system would function must be considered. Studies show that improvements in throughput, fuel consumption and emissions are still considerable even when the CAV market penetration is low (Jiang et al., 2017). If in the short term CAVs do prove to be more effective than conventional vehicles, it is likely that in the long term the amount of long distance trips taken by private road vehicles and commercial aircraft will decrease noticeably, and those by CAVs will increase significantly. Thus the impact of this rise in total vehicle trips on road networks is also uncertain and must be investigated (LaMondia et al., 2016).

Table 1 Summary of literature review for selected sub-topics

Source	Source type	Sub-topic			Position on CAVs			Key findings
		ATC	APF	PAT	+ve	Neutral	-ve	
Alessandrini et al., 2015	Journal article		X		X			▪ CAVs could potentially reduce space needed per vehicle in parking facilities by 75% compared to current requirements
Bansal & Kockelman, 2017	Journal article			X			X	▪ Market penetration of Level 4 CAVs could be anywhere between 24.8% and 87.2% by 2045 ▪ Significantly influenced by rate of price drop, rate of increase in willingness to pay and regulations on mandatory adoption
Basar & Cetin, 2017	Journal article	X			X			▪ Survey results show no clear rejection of descending price auction-based tolling ▪ When travel time savings are 30 minutes, revenue is 70% higher and capacity utilisation is improved when compared to fixed tolls
Böhm & Frötscher, 2008	Working paper	X			X			▪ Dynamic tolling systems which charge vehicles based on route and lane could reduce congestion, travel times and pollution
Cetin et al., 2017	Report	X				X		▪ CAVs will allow tolls to be varied based on time of day and congestion, and allow changes to be made to which lanes are tolled at what times ▪ Model favours toll operator, as utilisation and revenue maximised rather than pushing for best route for drivers
Clark et al., 2016	Report			X		X		▪ Governments, authorities and industry have a role in influencing adoption ▪ Willingness to pay for full automation will strongly influence adoption rate
Collins et al., 2015	Journal article	X					X	▪ Not a socially optimal system, as the operator revenue is maximised instead of providing the best solution for CAVs
Estepa et al., 2017	Journal article		X		X			▪ Double parking can increase a given area's parking capacity by 50%, and with CAVs will not be problematic ▪ Permitting CAVs to double park will also increase the probability of finding a parking space, reducing cruising time and emissions
Faheem et al., 2013	Journal article		X			X		▪ Centrally controlled parking facilities will help save fuel and time ▪ Also provides the opportunity to improve safety and theft protection
Fakharian Qom, 2016	Thesis	X				X		▪ "Managed lanes" are effective under high demand and high market penetration ▪ With low market penetration, the benefit is not great due to the small potential increase in capacity
Ferreira et al., 2014	Conference paper		X		X			▪ Total distance covered by vehicles in an automated parking facility can be reduced by 30% compared to conventional facilities ▪ Space required is almost half of that needed for conventional facilities
Klemm et al., 2016	Conference paper		X		X			▪ Will allow passengers to leave vehicle before finding a parking space, and vehicle can be charged automatically without human input
Lavasani et al., 2016	Journal article			X		X		▪ Higher market size leads to a higher rate of adoption

Source	Source type	Sub-topic			Position on CAVs			Key findings
		ATC	APF	PAT	+ve	Neutral	-ve	
								▪ Initial cost of CAVs with respect to that of conventional vehicles is not highly influential
Lavieri et al., 2017	Journal article			X		X		▪ Likelihood of early CAV adoption greater for younger, urban demographic, those with green lifestyle, tech-savvy people ▪ Areas of higher density more likely to see higher level of shared CAV adoption and reduced ownership
Le Vine & Polak, 2016	Journal article	X				X		▪ Peer-to-peer tolling could result in social inequity, due to willingness to pay being linked to income level ▪ System could be taken advantage of for financial gain only
Levin & Boyles, 2015	Journal article	X			X			▪ Intersection auctions more favourable than first-come-first-serve, due to the randomisation of travel directions ▪ Reduced queues and travel times for all vehicles, as well as less congestion on high demand network links
Litman, 2017	Report		X			X		▪ CAVs will allow vehicles to park further away from passenger destinations than with conventional vehicles ▪ Parking costs may generally reduce due to reduced demand at centrally located facilities ▪ May cause negative environmental impacts if the cost of cruising around is less than that of parking
Menon, 2015	Thesis			X		X		▪ Based on a survey, 40% of respondents would use CAVs when they are implemented in society ▪ Perception of CAVs a major influence in the adoption rate
Nieuwenhuijsen et al., 2018	Journal article			X			X	▪ Market penetration of high-level CAVs could potentially reach 100% by 2050, but real adoption rate highly uncertain due to variables for different situations
Nourinejad et al., 2018	Journal article		X		X			▪ Parking facility space requirements can be reduced by an average of 62% and up to 87% using an optimised layout
Sharon et al., 2016	Conference paper	X			X			▪ Delta-tolling can reduce travel time by up to 35% compared to un-tolled roads, and 17% compared to roads with fixed tolls
Sharon et al., 2017a.	Conference paper	X			X			▪ Social welfare can be improved by up to 33% when delta-tolling is applied to a downtown road network
Sharon et al., 2017b.	Journal article	X				X		▪ System aims to improve social welfare, but simulations assume 100% responsiveness to tolls which will probably not be the real-world case
Solbraa Bay & Johannes, 2016	Thesis			X		X		▪ Very high variance in intentions to adopt CAVs ▪ Main influences on adoption intention are attitudes towards the technology and perceived compatibility
Timpner & Wolf, 2012	Conference paper		X		X			▪ Convenience of combining autonomous parking and automatic vehicle charging may make such a system more convenient and desirable ▪ Issues of short range due to electric battery capacity will be addressed

Source	Source type	Sub-topic			Position on CAVs			Key findings
		ATC	APF	PAT	+ve	Neutral	-ve	
Zhang & Guhathakurta, 2017	Journal article		X		X			▪ Based on a simulation in Atlanta, market penetration of just 5% would allow for a 4.5% reduction in land use for parking facilities ▪ Facilities with "charged-parking" would shift demand away from busy centres
Zhu & Ukkusuri Satish, 2014	Journal article	X			X			▪ Dynamic tolling based on distance and fluctuating traffic can reduce travel times on tolled links by 25%

Table 2 Overview of influencing factors on adoption rate
(Key: * = not directly relevant to CAVs, + = influence on adoption rate)

Source	Influencing factor on adoption rate							Comments
	Cost	Demographic	External environment	Market size	Perception / acceptance	Regulations	Willingness to pay (WTP)	
Al-Alawi & Bradley, 2013	+*	+*			+*			▪ Literature review of different models for PHEV adoption
Bansal & Kockelman, 2017	+					+	+	▪ Projected market penetration levels under different scenarios, with variations in rate of price decrease, rate of increase in willingness to pay and presence of CAV regulations
Choi & Ji, 2015					+			▪ Survey results for importance of trust on CAV adoption rate
Clark et al., 2016			+		+	+	+	▪ General overview of factors behind adoption ▪ Models behind perception and acceptance
Lavasani et al., 2016	+			+				▪ S-curve for market penetration of CAVs based on adoption statistics for past automotive and technological advances
Lavieri et al., 2017		+	+		+		+	▪ Survey results for the relationships between demographics and adoption intentions
Menon, 2015		+			+		+	▪ Survey data on demographics, perception and adoption intentions

Source	Influencing factor on adoption rate							Comments
	Cost	Demographic	External environment	Market size	Perception / acceptance	Regulations	Willingness to pay (WTP)	
Nieuwenhuijsen et al., 2018	+		+	+	+			▪ System dynamics vs agent-based modelling ▪ In depth system dynamics model for CAV adoption
Rezvani et al., 2015	+*	+*	+*		+*			▪ Behaviours behind EV adoption
Saarenpää et al., 2013	+*	+*						▪ Study of geo-demographic factors behind PHEV adoption rate
Solbraa Bay & Johannes, 2016					+			▪ Models for perception and acceptance of technology, with some survey results
Total	6	5	4	2	8	2	4	

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