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Article *in* IEEE Access · February 2021

DOI: 10.1109/ACCESS.2021.3056025

IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Received January 11, 2021, accepted January 19, 2021. Date of publication xxxx 00, 0000, date of current version xxxx 00, 0000.

Digital Object Identifier 10.1109/ACCESS.2021.3056025

Drivers and Barriers to Implementation of Connected, Automated, Shared, and Electric Vehicles: An Agenda for Future Research

AMIRSAMAN MAHDAVIAN[1], (Graduate Student Member, IEEE), ALIREZA SHOJAEI[2], SCOTT MCCORMICK[3], TIMOTHY PAPANDREOU[4], NAVEEN ELURU[1], AND AMR A. OLOUFA[1]

[1]Department of Civil, Environmental, and Construction Engineering, University of Central Florida, Orlando, FL 32816, USA
[2]Building Construction Science, College of Architecture, Art, and Design, Mississippi State University, Mississippi, MS 39762, USA
[3]Electrical Engineering Department Mechanical and Aerospace Engineering, University of Tennessee, Knoxville, TN 80309, USA
[4]Department of Urban Planning, University of California Los Angeles, Los Angeles, CA 90095, USA

Corresponding author: Amirsaman Mahdavian (amirsaman@knights.ucf.edu)

This work was supported by the University of Central Florida College of Graduate Studies.

ABSTRACT Several converging trends appear to reshape the way citizens and goods move about. These trends are social, including urbanization and population growth, and technological, such as increased automation and connectivity. All these factors influence the market for connected, automated, shared and electric (CASE) vehicles, which presents many opportunities and challenges. The pace of the shift to a profoundly penetrated market for CASE vehicles is far from secure. Such transformation depends on the development of technologies, consumer attitudes, and policies. An expanding body of research has investigated the potential social and behavioral results of deploying CASE vehicles. However, most academic literature to date concentrates on technological issues linked to these vehicles. There are several teams from federal and state agencies, OEMs, academia, startups, and consortiums working on this complex subject. This study investigates several academic papers, as well as federal and industry reports, considering all the stakeholders mentioned above. Its aim is to present a comprehensive picture of the implementation barriers and drivers of CASE vehicle usage and provide suggestions to solve them. The findings confirm that several issues are currently affecting the implementation of CASE vehicles on the road. Although there have been significant partnerships and collaborations between CASE vehicle stakeholders, namely technology companies, federal-state agencies, and academic scholars, considerable work is still required to solve the remaining barriers facing CASE-related technologies. This would enable decision-makers to create effective policies for future transportation networks and increase the speed of CASE vehicle market penetration to enhance road network's level of service.

INDEX TERMS Automated vehicles, connected vehicles, electric vehicles, road level of service, road vehicles, shared mobility, smart mobility, transportation, traffic network.

I. INTRODUCTION

The progression of vehicles consists of three phases: motorization, saturation, and automation [1]. Each stage incorporates an extensive collection of technological, economic, and social changes. As a result, the service level in a future transportation network will be considerably affected by various disruptive forces such as population, urbanization, economics, political trends and energy trends, as well as electrical, automated, and connected technologies. One crucial trend in developing automation and connectivity technology of vehicle intelligence is artificial intelligence (AI). The progression of AI in CASE vehicles has included various areas of science such as machine learning (including deep learning and predictive analysis), natural language processing (including classification and clustering, translation, and information extraction), speech (speech-to-text and text-to-speech), expert systems, planning, scheduling and optimization, robotics, and vision technology (image recognition and machine vision) [2]–[6].

The UN [7] reported that 2007 was the first time in human history that the global proportion of the urban population

The associate editor coordinating the review of this manuscript and approving it for publication was Shun-Feng Su.

was higher than 50%. The number of people in the world continues to grow, and because of the opportunities that cities offer, a growing percentage of the population is expected to move to urban centers. This trend will lead to significant transportation demand. The UN [7] has stated that the number of megacities (defined as cities with more than 10 million inhabitants [8]) is expected to increase from 28 in 2014 to 41 in 2030. McKinsey and Company [9] predicted that cities will gain 2.5 billion new residents by 2050. Hence, any long-term transportation planning will need to incorporate these significant future changes in urbanization and population growth. This growth becomes an issue of geometry, as there simply will not be enough road supply to accommodate all the privately owned vehicles or to cope with the ensuing congestion, pollution and other externalities caused by this model.

The U.S. economy extends across its constituent states, connecting to the rest of the world through the import and export of commodities and produced goods that aid both markets at home and overseas. External trade has grown more quickly than the overall economy, reflecting rapid global interconnectivity. The transportation division is a vital element of the U.S. economy, comprising roughly 9% of its gross domestic product (GDP). The size of this economy is expected to double between 2017 and 2045, which will lead to a continuous increase in vehicle miles traveled (VMT), reflecting increases in productivity and population [10].

The increased number of trips due to urbanization and population growth and economic and workforce changes should be addressed. One traffic congestion remedy that is swiftly emerging is CASE vehicle technology, which could significantly increase traffic capacity by decreasing headway between vehicles (due to connectivity technology) and enhance safety [11], [12]. Van Arem *et al.* [13] have demonstrated that penetration rates for connected and automated vehicles (CAVs) of less than 40% do not affect capacity. Hartmann *et al.* [14] also mention that the low market penetration rates of CAVs do not lead to obvious capacity benefits. Quantifying the impact that these forces can have on societies' quality of life is being delayed to a time when a significant number of CAVs are operating, which in turn leads to important decisions being postponed.

The benefits of CASE on their own handle the supply side but will not solve the demand side and thus call for a suite of complementary mobility management solutions (pricing, access fees, dedicated lanes for higher occupancy and smaller footprint vehicles) to ensure free flow.

The automobile sector is moving toward more digitalization and new business models. This has increased technology-driven trends such as advanced driver-assisted systems to reduce collisions and increase flow, automated driving, electrification, and connectivity [15]. The emergence of CAVs is vital to urban development and through a collaboration between public authorities and partners in the private sector, CAVs can enhance the quality of life of individuals [16]–[19]. In all likelihood, CAVs will have significant and immediate consequences on highway traffic capacity and flow [20].

Fagnant and Kockelman [21] predict that a 90% market penetration rate by CAVs could lead to yearly financial gains approaching $202 billion in the United States. Their analysis shows a 4.22 million decrease in yearly crashes and 217,00 lives saved through decreased human error. This would lead to an annual saving equivalent to $960 for every CAV driver. Certain gains, such as time saved due to shorter periods spent in traffic, more free time while in the car, and fuel savings, can additionally be monetized [22]. Nevertheless, there is still skepticism about the impact of such technologies on the level of service and the price of acquiring them.

In regard to the traffic network, traffic flow is the primary concern of citizens and the responsibility of the federal, state, and city governments. Traffic congestion is viewed as an entirely negative issue, and its elimination is a central preoccupation of administrative officials. Cohen and Cavoli [23] state that a laissez-faire method would lead to increased tra?c counts as a consequence of the increasing population of drivers and a likely rise in the kilometers driven by each traveler. The benefits from the rise in network efficiency anticipated from CAVs is also not guaranteed to occur without proper administrative interference. Additionally, there are many complex issues regarding the ability of these vehicles to handle mixed traffic. However, the predicted emergence of large robo-taxi fleets in the future, when they have sufficient density in a particular city or region, may enable cooperation with one another and influence the entire picture of congestion.

Infrastructure systems are approaching the limits of their capacity, creating a bottleneck for traffic networks [20]. Furthermore, if these trends continue, the number of trips would outpace the rate at which officials can accommodate them in terms of increasing the transportation system capacity [20]. There have been several efforts to reduce the impact of congestion by improving the selection of optimal routing ([24]–[28]), improving charging of an electric vehicle fleet, and also investing in intelligent and sustainable transportation and employing electric batteries to address pollution challenges [29]. Urban authorities are thus under growing pressure to prevent congestion. The impact of increased congestion on the U.S. economy was about $179B in 2017 [30], which can reduce the reliability of transportation facilities, increase vehicle operation costs, raise environmental and safety costs, and worsen roadway conditions.

Although researchers have begun to investigate the likely social outcomes of automated vehicle (AV) deployment, most of the articles to date focus on the technology-related aspects of CASE vehicles [31] and [32]. Both academic articles and industry reports offer few suggestions as to how this new technology can be administered, and only a handful of scholars have examined this issue [33]–[35]. Instead, the majority of research is involved in investigating the governance of this technology's initial advancements [36] and [37].

This study attempts to identify the main implementation challenges and issues regarding CASE vehicles and provides several suggestions and recommendations to solve them. The findings confirm that substantial challenges currently hinder the introduction of CASE vehicles onto the roads. However, there have been effective collaborations such as the Partners for Automated Vehicle Education (PAVE) [38], the Automated Vehicles Safety Consortium (AVSC) [39], and the Society of Automotive Engineers (SAE), as well as startups working with federal agencies. These main stakeholders must work together to solve the implementation of these emerging technologies. In particular, the government can leverage the advantages of CASE vehicles to improve the efficiency and level of service of roads by considering the importance of the impending disruptive forces and by solving the implementation barriers to adopting these vehicles.

II. RESEARCH METHODOLOGY

To implement a systematic critical literature review, the authors of this study first explored broad research trends in the literature via Google Scholar, using critical keywords concerning CAV implementation in transportation studies. Next, the authors examined peer-reviewed databases by utilizing selected keywords. The following keywords: ''automated vehicles,'' ''connected vehicles,'' ''electric vehicles,'' ''shared automated vehicles,'' ''CASE implementation barriers,'' ''CASE vehicles technology,'' ''CASE vehicles regulations, ''CASE vehicles user acceptance,'' and ''smart mobility implementation'' were employed at this stage of the research. This literature search was conducted using leading transportation research databases, namely Transportation Research Parts A through F (Elsevier), Sustainable Cities and Society (Elsevier), Transport Policy (Elsevier), Journal of Technological Forecasting and Social Change, Journal Transportation and Health (Elsevier), Journal of cleaner production (Elsevier), Transportation Research Record, Transport Reviews Journal (Taylor & Francis), and the Transportation Research Institutes. To gain information about the system dynamics related to the topic, the authors also reviewed reports and articles prepared by either transportation consulting companies or the National Highway Traffic Safety Administration (NHTSA), and the Federal Highway Administration (FHWA).

Furthermore, as this topic is evolving rapidly, in order to better capture the current state of knowledge and practice the authors included the NHTSA's Automated Driving Systems (ADSs – SAE International Automation Levels 3-5) Voluntary Safety Self-Assessment (VSSA) Disclosure Index in the review process. Additionally, this study carefully reviewed National Science Foundation (NSF) [40] requests for proposals (RFPs) to identify the current gaps in this field. Although most of the focus of the study is on articles, projects, research, and reports published in the U.S., several studies from European countries and China have been included in the review process. An inclusion and exclusion range were set to appraise the relevance of each study to the topic and was then applied based on the content of each paper. First, the authors identified and eliminated manuscripts that did not report research specifically on drivers to CASE vehicle implementation. Second, the authors studied the remaining selected articles that addressed topics related to barriers in implementing CASE vehicles. The authors critically reviewed 131 articles (56 journal papers, 16 conference papers, 19 transportation research institutes, 16 federal reports, and 24 industry reports) to explore the various stakeholders' viewpoints regarding the subject of research from among the 367 articles initially identified.

III. LITERATURE REVIEW

CASE vehicles present many opportunities and benefits as well as challenges that will ultimately lead to new behaviors in the traffic network. This section aims to review the studies conducted by academia and industry about the implementation barriers and drivers of CASE vehicles, mainly in the U.S.. The speed and nature of transitioning to a well-penetrated market of CASE vehicles is unpredictable [21]. The transition depends largely on technological maturity, consumers' attitudes (i.e., acceptance rate), and policies.

A. TECHNOLOGICAL MATURITY

Technological development is the first and main step in the implementation of the CASE vehicle market. With access to technology, other steps – such as regulations – can frame the CAV transition package and prepare it for presentation to consumers. McKinsey and Company [15] state that the automobile sector is undergoing a revolution regarding digitalization, with waves of new business models. This has given rise to new technology-driven trends. Atkins [16] report that the emergence of CAVs is one of the most compelling developments ever to affect cities. As a result, CAVs and electric vehicles (EVs) are a developing reality that must be carefully studied.

1) ELECTRIC VEHICLE TECHNOLOGY

One of the few advantages advantage that fossil fuel-using personal vehicles retain over electric vehicles is the time required to fill up or recharge. Notable efforts have been made to addressing pollution problems and fuel shortages. Transportation agencies in several countries have provided different energy sources as alternatives to fossil fuels, such as electric, hybrid technologies, biodiesel, and hydrogen, to deliver an eco-friendlier environment [29]. Notably, vehicles entirely or partly driven by electricity are on the rise and hold great potential value. In 2019, 41% of U.S. citizens were interested in alternative powertrain technology, whereas only 29% wanted something other than gas or diesel [41]. The change in principal global customer demand is the result of lower operational costs and emissions. The main concerns for fleet electrification that remain include the cost of battery technology, battery life, the number of charging stations, and charging wait times.

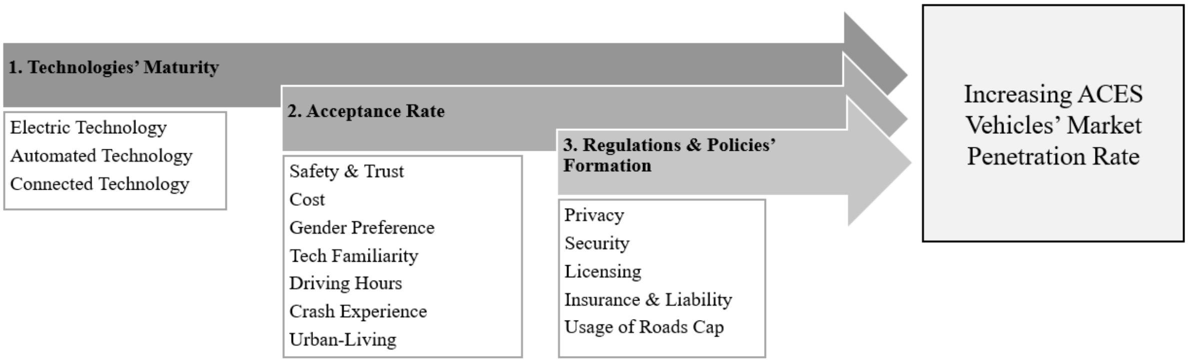

FIGURE 1. CASE vehicle drivers.

The energy efficiency approaches of electric vehicles based on the system modeling method can be categorized into two groups. The first includes EV models considering longitudinal vehicle dynamics [42], [43], in which the consumed energy is calculated by integrating power consumption over time. The second comprises EV models considering the longitudinal vehicle dynamics and electric motor dynamics [44], in which the energy consumption is calculated by the efficiency between the drive energy and the regenerative energy. A dynamic model of an EV system commonly includes a battery (lithium-ion battery or lead-acid battery), an electric motor, a gear train, and longitudinal vehicle dynamics, named the powertrain system. The various models can be displayed as SMK-1, SMK-2, IMK-1, IMK-2, IMK-3, and IMK-4 [27]:

- SMK-1: Simple Model with Rigid Shaft
- SMK-2: Simple Model with Flexible Shaft
- IMK-1: Integrated Battery Electric Vehicle (IBEV) Model with Rigid Shaft & Lithium-ion
- IMK-2 IBEV Model with Rigid Shaft & Lead acid
- IMK-3: IBEV Model with Flexible Shaft & Lithium ion
- IMK-4: IBEV Model with Flexible Shaft & Lead acid

Bloomberg New Energy Finance and McKinsey [45] state that the cost of lithium-ion batteries dropped roughly 65% between 2010 and 2015 and is expected to fall to a low-range cost of $50 per kilowatt-hour by 2040. This would eliminate the price and performance gap of CASE vehicles compared with internal combustion models. Researchers also predict that by 2040, one in three new cars sold worldwide will be fully electric. Battery costs have decreased to $273/ (kWh) from $599/ (kWh) in 2013 [46]. These costs are expected to drop even more, possibly reaching as little as $100/ (kWh) by 2026, rendering them a highly attractive choice for consumers. By 2030, a second tipping point will occur as the cost of batteries for battery electric vehicles (BEVs) will decline rapidly [1].

The drivers behind CASE vehicle market penetration are shown in Figure 1.

2) AUTOMATED VEHICLE TECHNOLOGY

Automated vehicle (AV) technologies are electronic systems that affect the control of the longitudinal and lateral movement of a vehicle, as well as acceleration, geolocation, braking, and sensing via cameras, sensors, radar and lidar, demanding a high degree of precision. They are nuanced and complex, requiring an integrated relationship between hardware and software. In these technologies, vehicle software is as necessary – if not more important – than vehicle hardware. Moreover, AVs cannot require connected vehicle technology to function since they must be able to navigate the road network autonomously.

automation drawn up by the Society of Automotive Engineers (SAE). Moreover, the National Highway Transportation Safety Administration (NHTSA) also publishes AV policy guidelines. A broadly accepted policy for AV classification, authorized by the NHTSA first in 2013 and then updated in 2018, is comprised of five levels, ranging from no automation to full automation. In 2014, the SAE created a separate classification for AVs with the J3016 standard. SAE International [47] also offers an industry viewpoint on AVs and their classification is comprised of six levels. The levels are determined by the corresponding role of the AV system versus the driver and consist of fallback responsibility for the driving task, monitoring of the environment, steering and acceleration, and driving mode. The automation levels include: no automation (Level 0); driver assistance (Level 1); partial automation (Level 2); conditional automation (Level 3); high driving automation (Level 4); and full automation (Level 5) [47].

3) CONNECTED VEHICLE TECHNOLOGY

Connected vehicle (CV) technology is an information exchange platform that allows highway infrastructure and cars to convey data back and forth to reduce collisions, optimize traffic management, and provide travel information. Broadly, a CV system facilitates the wireless transfer of digital data within a car and its outside environment. This technology converges diverse hardware and software, enables bidirectional communication using protocols, and gives access to any device inside and outside the vehicle. The permanent connectivity enables smart information management which is the key to zero emissions and zero collisions goals [48].

Forms of unidirectional communication includes satellite radio, global positioning systems (GPS), near field communication (NFC), and AM/FM/HD Radio. On the other hand, bidirectional communication includes cellular technology for diagnostics and communications, Wi-Fi for information, DSRC for safety, NFC for authentication, and Bluetooth for entertainment. Bidirectional communication has various uses such as safety, mobility, and infotainment, each of which has different requirements for speed, security, distance, and bandwidth [48].

Telematics is an interdisciplinary field that incorporates telecommunications, vehicular technologies such as road transport and road safety, electrical engineering, and computer science. General Motors (GM), with the OnStar, and Ford, with Sync, have the highest penetration in the market. Hyundai, with BlueLink, and Mercedes-Benz with ConnectedDrive, are the next players in the U.S. market [49]. The telematics service providers offer tethered, embedded, and mirrored technologies. For tethered systems, the vehicle uses cellular radio in smartphone hardware or Bluetooth (such as Apple CarPlay, Android Auto, and MirrorLink). In the case of embedded systems, the original equipment manufacturer (OEM) contracts with the wireless network operator to support built-in cellular radio (such as AT&T and Verizon in the U.S.) [49].

The connectivity services that have been offered the most to customers include infotainment and convenience, navigation, safety, security, and maintenance. Moreover, driving style recognition (DVR) and EV-related features are upcoming features in the realm of connectivity. However, there are some aspects, such as insurance and urban mobility-related features, that need to be investigated more fully.

The communication protocols used include Bluetooth, Wi-Fi, satellite, DSRC, and cellular-5G. Bluetooth is only capable of data transfer over a 10-meter range, has limited functionality, and requires pairing. Wi-Fi also has some security issues. Satellites are expensive to develop and maintain and typically communicate unidirectionally. The dedicated short-range communication (DSRC) is a wireless transmission protocol that enables the sending and receiving of data within a 1,000-meter range. The DSRC is extremely fast, secure, and bidirectional with no usage cost. The high reliability, increased safety, and security levels supporting the vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) are among the DSRC deliverables. The technologies involved include:

- Sensors such as radar, lasers, high-powered cameras, sonar, and light detection and ranging (Lidar) technology
- Advanced software that examines the data
- GPS technologies that assist positioning, routing, and navigation in the CV environment

In addition, there is 5G, which is the fifth generation of the wireless broadband technology based on the IEEE 802.11ac standards. It is estimated that 5G provides speeds 100 times faster than 4G/LTE and better coverage with a 5GHz signal of up to 10Gb/s. 5G increases the network potential by up to hundreds of connections [49]. The expansion of 5G technology and DSRC could deliver intelligent transportation, connecting CASE vehicle data to transport infrastructure and the cloud. The U.S. Department of Transport (USDOT) has funded deployments of CV technology and transfers digital code over a licensed radiofrequency of 5.850 - 5.925 GHz, in an example of DSRC utilizing a language certified by SAE International 2018. It is important to note that compliance to SAE standards is optional and no government has incorporated them into regulations yet.

Innovative technologies in the realm of advanced driver assistance systems (ADAS) have been devised to both enhance highway safety and expand traffic capacity [50]. This level of ADAS is suitable for purposes such as forward-collision alert, lane-keep support, and blind-spot monitoring. A recent review by the AAA Foundation for Traffic Safety [51] stated that ADAS decreases crashes, injuries, and deaths involving passenger vehicles. This would result in the elimination of 37% of injuries, and 29% of deaths. These intelligent-vehicle systems comprise four categories, namely AV, CAV, cooperative adaptive cruise control (CACC), and adaptive cruise control (ACC). Established ADAS technology can recognize some objects, informing the driver of dangerous highway situations and slowing down or even stopping the car [52].

B. USER ACCEPTANCE RATE

With the CASE technology in place, users are expected to accept this technology as a replacement for their daily means of transportation if CAV is to gain high market penetration. Deloitte (2018) [53] states that critical parameters to the user approval of CAV technologies will be cost, brand trust, and safety. Currently, there are still large gaps preventing the full adoption of CAV technologies. First, individuals need to accept technology as safe, secure, and reliable. Second, individuals must find CAV technologies interesting enough to motivate their willingness to pay (WTP). Other related variables that may correlate with the acceptance of CAV should be considered, including gender, income, and "tech-savviness" [54]–[56].

1) SAFETY AND TRUST

Zmud *et al.* [57] report that the leading reason for an individual not to reliably use technology is a lack of trust in that technology. Bansal *et al.* [46] report that an approved safety history increases the likelihood of U.S. consumers driving a CAV by 71%. This figure is up from the previous 68% reported in 2015.

2) COST AND WTP

Generally, drivers and passengers have different values regarding travel time and are therefore likely to display a different WTP concerning the addition of CAV technologies to their vehicles. Cost is a common variable in choosing travel options. There are two types of costs here to consider: upfront cost, and cost per mile. HERE [58] reports that consumers are also susceptible to the price of CAVs. As a result, the current high cost of CAVs is a critical hurdle that must be overcome before mass production and adoption rates can increase [21]. The upfront costs of automated and EV technologies are currently higher than those of traditional internal-combustion-engine passenger vehicles. However, the cost of AVs is expected to fall rapidly in the decade from 2020 onwards, owing to breakthroughs in sensor and battery technology [1]. Cost and WTP issues can be divided into categories of cost to buy and cost to access.

a: COST TO BUY

The idea that customers will buy AVs in the future is an assumption that is yet to be supported by changing demographics and ownership preferences. However, there are several reports about price changes of various elements of AVs. Regarding AV upfront price reduction, Waymo [59] reports that LIDAR cost approximately $75,000 several years ago but the price dropped to $7,500 in 2017. The U.S. Environmental Protection Agency (EPA) [60] and NHTSA [61] also report that automated manual transmission, which facilitates truck shifting, was priced at approximately $5,100 in 2013 but dropped to $3,750 in 2018. The DOT (2014) [61] has reported a price drop in adaptive cruise control (ACC) from nearly $3,000 in 2006 to $2,000 in 2014. The Texas A&M Transportation Institute [62] similarly estimate that, by 2030, new technology could reduce the cost of full autonomy to be less than $1,000 per vehicle.

b: COST TO ACCESS

Concerning CAV cost per mile, the widespread adoption of CAVs may lead to a decrease in individual vehicle ownership as more individuals opt to employ shared mobility. The per-mile cost to operate these vehicles is projected to be substantially lower for highly autonomous and EV vehicles than for traditional internal-combustion-engine passenger vehicles [63]. ARK Investment Management LLC [64] has studied the cost of various modes of transportation and the results indicate the price per mile is $3.50 for taxis, $0.70 for personal vehicles, and $0.35 for autonomous taxis. It is worth noting that the research and development costs of CAVs should be added to the above-mentioned operational costs.

3) AGE FACTOR

Research suggests that younger drivers, regardless of nationality, are interested in owning CASE vehicles [57]. A survey conducted by Bansal *et al.* (2016) [46] indicated that 70% of individuals from Generation Y/Z in the United States would be more inclined to purchase a CASE vehicle produced by a trusted brand than a traditional vehicle from a separate brand. Individuals from Generation X, meanwhile, showed a slightly lower acceptance rate of 62%.

4) GENDER FACTOR

Concerning gender, various studies report that men are more likely than women to acquire a CASE vehicle [65], [66]. This gender-specific preference is indicated by men's tendency to acquire vehicles earlier, willingness to pay more for new technologies, and their stronger belief in the safety of AVs [67].

5) FAMILIARITY WITH TECHNOLOGY

In general, tech-savvy individuals show a greater likelihood of being CASE vehicle consumers [58], [46]. Regarding the number of passengers, individuals who drive alone demonstrate the greatest interest in the latest technologies and show the greatest WTP, with little dependence on others' adoption rates [46]. Concerning crash experience, individuals who have survived crashes have an interest in and WTP for the latest technologies, with little dependence on others' adoption rates [46].

Regarding issues of urban sprawl, Gurumurthy and Kockelman [68] report that drivers with lengthier commutes tend to prefer privately owned automated vehicles. Regarding shared automated vehicles (SAVs), moreover, middle-income households prefer renting SAVs for long-distance journeys. SAVs are also preferred by customers for long-distance business trips of less than 500 miles. Moreover, the absence of a driver's license profoundly improves the willingness to share rides with strangers. Ultimately, the authors state that those with higher incomes and are younger in age are also much more likely to share rides in SAVs. It should be noted that the authors believe that people in general like private mobility, which could be private ownership or private access to shared fleets.

C. REGULATIONS AND POLICIES

The third factor that can accelerate or slow CAV purchases is regulation and policy formation. Regulations represent additional hurdles for CAV implementation, as a result, a framework to utilize these technologies more efficiently is needed. For legislators to design effective policies for the robust employment of CAVs, a set of legal, social, and ethical concerns need to be assessed along with their influences. Once these challenges are met, however, CAVs can offer a substantial value for consumers.

1) PRIVACY

CAVs will run highly sophisticated and advanced onboard computing systems that can transfer a vast amount of data about their users and their location to third parties. Electronic security, therefore, is likely to be a concern for automobile producers, prosperous CASE vehicle consumers, and transport decision-makers. The smart mobility network of a CAV could be vulnerable to dissatisfied employees or hackers who could create crashes and cause traffic congestion turmoil or threaten to do so. As a result, concerns about connectivity, privacy, and data security remain an important and pressing issue. Users are divided on whether the benefits of increased connectivity in their vehicles are worth the risks. For now, solutions regarding CASE vehicle data collection, ownership, and accessibility are unclear. When American users ranked their choices for stakeholders they would trust to maintain CASE vehicle information, the results were as follows: OEM 26%; no-one 26%; dealer 9%; government 5%, and other 34% [41]. These numbers indicate a distrust in the government regarding data ownership and show that data security is a challenging issue for the wider adoption of CAVs.

2) LICENSING

There is still no consensus on the need for additional drivers' license certifications or classes to operate CASE vehicles. Moreover, if individual drivers are obliged to receive a second license for CAVs, this could represent an additional hurdle for increasing market penetration and usage, especially if an extra cost is associated. USDOT AV4.0. Reference [69] has discussed the idea of licensing users based on the level of automation they can handle. For example, the authors believe that today's elderly may be a level 0, but a child would be in Level 4 and above.

3) INSURANCE AND LIABILITY

CASE vehicle collisions represent a complicated issue of liability in the event of a CAV hitting a pedestrian or colliding with another CAV. Current tort law fully covers what is needed for CAVs. USDOT AV4.0. Reference [69] states that with regard to the individual piloting, the vehicle is liable; but if the car is autonomous, the builder of the car is liable. However, these issues will ultimately be established in courts as precedent cases start to appear5.

IV. DISCUSSION

While global urbanization, the sharing economy, smart cities, and clean energy present challenges, these trends also drive the need for innovation and new technologies. CAVs, CATs, and smart roads seemed futuristic just a few years ago yet are rapidly becoming the new normal. Technology can optimize people's travel experiences, make roads safer, and shorten delivery times.

By 2050, it is forecast that 66% of the global population will be living in urban areas [2]. Currently these areas hold 55% of the population, meaning that they will need to cope with a growth of 2.5 billion people. To accommodate the additional needs of their rising populations, cities must become more efficient and sustainable. The predicted gains in efficiency brought on by CASE vehicles, such as increased traffic capacity, will not occur with low market penetration rates ([11], [14] and [70]). Van Arem *et al.* [13] state that traffic capacity enhancements would not occur if market penetration rates are lower than 40%.

This section first discusses the various CASE market's stakeholders and their expectations and goals, then moves on to discussion of standards, consortiums, and programs. Next, CAV market penetration predictions are investigated from the standpoints of "sales and cost", "VMT", "vehicle fleets", and "ownership and access". Then, the current trends for CASE vehicles are discussed, followed by an investigation of the obstacles to CASE vehicle implementation in four aspects: technology, user acceptance, regulations, and smart city formation. Finally, suggestions and recommendations to facilitate the implementation of CASE vehicles are presented.

A. STAKEHOLDERS

The CASE market includes various stakeholders, including consumers, OEMs, wireless carriers, software developers, and the government. People want to utilize technology in their everyday life to enhance safety and provide accurate voice command. They are also interested in the relevant features for instant and reliable access [49]. They look for streaming music for in-car use as well as access to social media while in the car. Moreover, they want features that warn them about collisions, fatigue, and mechanical errors. The OEMs, for their part, want to increase their sales and recurring revenue streams (such as subscriptions and services) while decreasing their liability (by increased safety and smart app integration) [71]. The wireless carriers want to get ahead of the competition and make alliances with OEMs to increase their revenue. They continuously look for chances to produce competitive products and services to align with innovative features, support the community, and progress technology to get a higher portion of the market [71].

Software developers look for more data to develop location-based services in order to tie the head unit to the traffic network points more easily, using enhanced human-machine interface (HMI) to mobile integration services.

The government has different sections with different needs and requirements for the CASE vehicle market. The NHTSA put out a notice of proposed rulemaking (NPRM) in 2017 regarding V2V, while the Department of Transportation (USDOT) is looking for ways to increase the safety of roads and enhance routing, weather, and traffic information communications. In the U.S., USDOT sponsors CV research for safer, smarter, greener surface transportation. The Intelligent Transportation System Joint Program Office (ITS-JPO) is a pioneer in this area of studies. Moreover, the Department of Defense (DoD) demands high security levels for CASE vehicles. Lastly, the Department of Energy (DoE) seeks environmental improvements employing CASE vehicles (USDOT ITS-JPO 2020).

B. STANDARDS

The key organizations that set the standards for connected vehicle protocols are the SAE, ITU, and IEEE. SAE J2945/1 specifies the system's minimum requirements and characteristics employed on the interface needed to develop interoperability between on-board units for V2V safety systems. Additional SAE Automotive Electronic Systems Reliability Standards include J1938, J3083, and J1879 [47]. The SAE J1938 standard can be used as the basis of the product development process and checklist for vehicle electronic systems. SAE J3083 could be used as guidance for reliability predictions conducted on automotive electronics products. The SAE J1879 is for robustness validation of semiconductor devices in automotive applications [47]. Additionally, the International Telecommunication Union (ITU) allots satellite orbits and parts of the global radio spectrum, generates the technical standards that guarantee that networks and technologies seamlessly interconnect, and enhances access to information and communication technologies (ICTs) to perceive communities globally. Ultimately, the IEEE 802.11 standard supports communication in 5GHz bands, specifically 5.850-5.925 GHz within North America, to enhance mobility and safety of all forms of surface transportation (IEEE 802.11 2016). It should be noted that complying with existing standards, as of now, is not mandatory when it comes to message sets and formats. However, the radio aspects of the IEEE 802.11 level are standardized and all makers of radios adhere to these standards by cross-industry agreement.

C. CONSORTIUMS

Fifteen major groups are aligning around different aspects of connected vehicles [49]. The VII Consortium (VIIC) was an early industry consortium consisting of 10 light-duty vehicle manufacturers. VIIC was established to plan, develop, and test a proposed vehicle infrastructure integration system designed to improve the safety and efficiency of U.S. automobile traffic. The Crash Avoidance Metrics Partnership (CAMP) was formed by Ford and General Motors in 1995 to enhance traffic safety by implementing crash avoidance countermeasures in passenger vehicles. Currently, CAMP is a joint effort by USDOT and five major automakers (Ford, GM, Mercedes-Benz, Toyota, and Honda). They developed the first V2I prototype safety system, based on DSRC, ready for field operation trial in the U.S. The Connected Vehicle Trade Association (CVTA) was formed in 2005 at the request of the automakers participating in the VII Consortium to provide a business language where all industries needed to build a complete ecosystem could collaborate. OmniAir Consortium advocates for the development and promotion of certification for intelligent transportation systems (ITS). The Car 2 Car Communication Consortium (C2C) is an open European standard for C-ITS that validates the process focusing on V2V systems and V2I communications. The Car Connectivity Consortium (CCC), meanwhile, is a non-profit organization that believes apps and dashboards should make driving safer by minimizing distractions and maximizing ease of use via the connection between cars and smartphones. The GENIVI Alliance is another non-profit industry alliance advocating broad adoption of the In-Vehicle Infotainment (IVI) open-source development platform. GENIVI aims to align requirements, deliver reference implementations, and offer certification programs [72]. The Wi-Fi Alliance is another a global non-profit association established in 1999 to encourage the best user experience with new wireless networking technology [73].

The Wireless Association (CTIA) was founded in 1984 to provide testing equipment and hardware certification programs so that consumers could enjoy the benefits of telecommunications technologies. The Open Mobile Alliance (OMA), formed in 2002, develops programs to test products to ensure industry-wide interoperability. The Consumer Electronics for Automotive (CE4A) was founded after five German car manufacturers took steps towards standardizing the interfaces between mobile devices and automotive electronic control units (ECUs). The Shanghai Vehicle Connectivity and Telematics Alliance (SVCTA) was established under the guidance of the Shanghai Information Technology Commission, the Shanghai Automotive Group, and the Shanghai Traffic Electronics Industry Association to improve the capability of independent innovation, to solve technical bottlenecks hindering industrial development, and to promote optimization and upgrading of industrial structure.

The Open Automotive Alliance was established in 2014 to make technologies used in the car safer, more seamless, and more intuitive for users. They are trying to develop a common platform that encourages innovation in the car industry, offers openness, customization, and scale, and allows automakers to bring cutting edge technology to their drivers easily. Ultimately, the telematics valley also supports and strengthens the development of business, technology, and the region as a premier telematics development cluster to provide a forum for the exchange of content and ideas [73].

D. PROGRAMS

There are some programs led by USDOT where the viability of connected vehicles is being investigated. Its goal of zero fatalities is one of the leading drivers toward studying CVs. Moreover, traffic managers have data to assess transportation and traffic performance in real time accurately. Additionally, the optimization of fuel efficiency is another driver of such research. USDOT has six areas of parallel research including V2V communication for safety by NHTSA, V2I Communication safety by FHWA, Dynamic Mobility Applications (ITS-JPO/FHWA), Road Weather Management (ITS-JPO/FHWA), Application for the Environment (ITS-JPO/FHWA), and Real-Time Data Capture and Management (ITS-JPO/FHWA) (USDOT ITS-JPO 2020).

The Vehicle Infrastructure Integration (VII) Proof of Concept (POC) Program was initiated in 2005 with the VII consortium to test 5.9GHz. The POC development test environment (DTE) were conducted in the suburbs of Detroit, MI. The key objectives of VII POC are to validate the SAE and IEEE standards, provide core services, support the simultaneous operation of safety, mobility, and commercial applications, and demonstrate security and privacy against malicious intrusions. Highway Infrastructure Planning is an alliance between AASHTO, the Vehicle-to-infrastructure deployment coalition (V2I-DC), FHWA Infrastructure Planning, and FHWA Road Weather Management.

The Connected Vehicle Safety Pilot Program was founded in 2011 by USDOT and the University of Michigan

Transportation Research Institute (UMTRI) to test CV operations in real-world situations, perceive how regular drivers utilize CV technologies, and discovering the safety advantages of CVs. Two elements of the safety pilot program are safety pilot driver clinics and safety pilot model deployment. The Southeast Michigan Test Bed was implemented in 2007 as the development and test facility for POC to determine the feasibility and limitations of DSRC operating at the 5.9GHz bandwidth. As the VII pilot program grew, so USDOT initiated an Affiliated Connected Vehicle Test Bed to act as a repository of data, specifications, overviews, and reporting points to collectively assemble all the information about ongoing programs for public access. USDOT organizes the association of 5.9GHz DSRC infrastructure equipment producers, workers of V2I installations, and the deployment of connected vehicle infrastructure components [73].

Mobility Transformation Center (MTC) is an administrative shell under which Michigan City (M-City) operates. The MTC's goal is to develop an advanced system occupying 32 acres on the University of Michigan's North Campus Research Complex. The M-City simulates a wide variety of complexities that vehicles might encounter in urban and rural areas. The American Center for Mobility is a 335-acre historic Willow Run site in Southeast Michigan focused on the testing, verification, and self-certification of CAVs [73].

E. CAVs MARKET PENETRATION PREDICTIONS

Given the cost and longevity of most vehicles, customers rarely consider new cars as a way to acquire modern technology. Hence, shifts to new technology generally take decades to penetrate the vehicle market fully. Innovations frequently follow a familiar deployment pattern, usually identified as an S-curve or Gal's Insight, and AV technology is also expected to follow this pattern [74]. Table 1 illustrates the sales and cost predictions of AVs from the reviewed literature for 2025 to 2060, grouped in five-year intervals. It is evident that most researchers agree that, as time passes, the market share of AVs will increase, and that after 2040 AVs will constitute the majority of cars on the roads.

Table 2 also shows the VMT and use predictions from the reviewed literature for 2025 to 2060 in five-year increments. Excluding the study by Hars (2014), there is an agreement among researchers regarding VMT and the use of CAVs. Lavasani's [77] predicted more conservative changes in market penetration rates in VMT and use compared with those of [76].

Table 3 represents vehicle fleet predictions from the reviewed literature for 2025 to 2060 in five-year increments. There is a consensus between researchers regarding the market penetration of vehicle fleets. However, the fleet percentage increase rate is lower than the use, ownership, and sales predictions.

Table 4 represents the vehicle-ownership predictions from the reviewed literature for 2025 to 2060. It is evident that forecasts for ownership and access are higher than the fleet, use, and sales rates. There is agreement among researchers that people will own automated vehicles and have access to CAVs by 2030. Moreover, there is a five-year difference regarding when 100% level 4 automation would happen, according to studies by Morgan Stanley (2013) and Rowe (2015).

TABLE 1. Sales And Cost Forecasts.

Year	Study	Forecast
2025	Citi GPS [75]	$40B market for level 4 AVs
	McKinsey [4]	33% of new trucks sold have level 4 or better
	Litman [76]	17% U.S. vehicle sales in AVs
2030	Lavasani [77]	2-5% of vehicle sales in AVs
	Litman [76]	23% of U.S. vehicle sales in AVs
	Lux Research [78]	$21B revenues for U.S. of selling level 2 & level 3 AVs
	Goldman Sachs [79]	42% new U.S. AVs Level 3, and 17% level 4 or 5
	Morgan Stanley [80]	$6000 per vehicle to add level 3 automation
2035	Lux Research [78]	250,000 vehicle sales annually for level 5 AVs
	ABI Research [81]	50% of all new vehicle sales in level AVs
	Mosquet et al. [82]	10% of U.S. new light-vehicle sales level 4 AVs
	HIS Automotive analyst	50% of U.S. and Canadian vehicle sales in AVs
	Litman [76]	35% of U.S. vehicle sales in AVs
2040	Lavasani [77]	20-40% of vehicle sales in AVs
	Litman [83]	50% of U.S. vehicle sales in level 4 AVs
2045	Morgan Stanley [80]	$10000 per vehicle to add level 4 automation
	Lavasani [77]	40-60% of vehicle sales in AVs
	Litman [76]	65% of U.S. vehicle sales in AVs
2050	Deloitte [84]	80% of sales for shared vehicles
	Litman [83]	75%-90% of U.S. vehicle sales in AVs
2055	Lavasani [77]	80-100% of vehicle sales in AVs
	Litman [76]	95% of U.S. vehicle sales in AVs
2060	Litman [76]	88-97% of U.S. vehicle sales in AVs

TABLE 2. Vmt and Use Forecasts.

Year	Study	Forecast
2025	Lavasani [77]	1-4% of vehicle travel in AVs
	Litman [76]	16% of U.S. vehicle travel in AVs
2030	Hars (2014)	90% of person-trips in U.S. in level 4 AVs
	Litman [76]	20% of U.S. vehicle travel in AVs
	Lavasani [77]	10-30% of vehicle travel in AVs
2035	Litman [76]	30% of U.S. vehicle travel in AVs
	Trommer [85]	Fleet share of AVs can be up to 42% in Germany in 2035
2040	Litman [83]	40% of U.S. vehicle travel in level 4 AVs
2045	Litman [76]	50% of U.S. vehicle travel in AVs
2050	Litman [83]	65% of U.S. vehicle travel in level 4 AVs
2055	Lavasani [77]	50-80% of vehicle travels in AVs
	Litman [76]	65-75% of U.S. vehicle travel in AVs
2060	Litman [76]	75-90% of U.S. vehicle travel in AVs

TABLE 3. Vehicle Fleet Forecasts.

Year	Study	Forecast
2025	Lavasani [77]	1-2% of vehicle fleet in AVs
	Litman [76]	9% of U.S. vehicle fleet in AVs
2030	Litman [76]	15% of U.S. vehicle fleet in AVs
2035	Lavasani [77]	10-20% of vehicle fleet in AVs
	Fehr and Peers [86]	25% of U.S. vehicle fleet in AVs
	Litman [76]	31% of U.S. vehicle fleet in AVs
2040	Litman [73]	30% of U.S. vehicle fleet in level 4
	Bansal [87]	43% of U.S. vehicle fleet in AVs
2045	Lavasani [77]	20-40% of vehicle fleet in AVs
	Bansal [87]	Fleet of light-duty vehicles in the U.S. will not be near homogenous by 2045
2050	Litman [76]	50% of U.S. vehicle fleet in AVs
	Talebian [88]	Automobile fleet will be near homogenous in about 2050 only if CAV prices decrease at an annual rate of 15% or 20%
2055	Lavasani [77]	40-60% of vehicle fleet in AVs
	Litman [76]	60-65% of U.S. vehicle fleet in AVs
2060	Litman [76]	70-85% of U.S. vehicle fleet in AVs

TABLE 4. Ownership and Access Forecasts.

Year	Study	Forecast
2030	Lux Research [78]	92% of vehicles, level 2 automation, and 8%, level 3
	Morgan Stanley [80]	100% of U.S. light-duty vehicles in level 3
2035	Harrop and Das [89]	8.5 million vehicles in AVs
2040	IEEE [90]	75% vehicles in AVs
2055	Morgan Stanley [80]	100% of U.S. light-duty vehicles in level 4
2060	Rowe [97]	100% of U.S. vehicles in level 4
	Fehr and Peers [86]	75% of U.S. highway traffic in AVs

Every year, essentially only 6.7% of the national fleet is being replaced. At that rate, it will take almost 14 years to reach a high penetration rate (90%) if all makes and models of OEMs start at the same time [92].

F. CURRENT TRENDS IN CASE VEHICLES

At the time of writing, the automotive industry is moving away from CASE vehicles hype. A more realistic understanding of the hurdles regarding their implementation and what kinds of automation will be available and when has developed. There have been several industry consolidations and partnerships among network and automobile companies to develop a critical mass in the new CASE technologies. However, investments by federal agencies remain less than private investments. Developers and investors tend to focus on narrowly defined use cases. Empirical evidence suggests we are far from level 5 automation (autonomous vehicles). A few experimental automation product use cases include the following:

- Low-speed urban first- or last-mile transit access
- Low-speed urban package delivery such as buses in protected busways [93]
- Trucks on low-density rural motorways, whether individually or as platoon followers; protected sites such as mines and ports [93]
- Taxi services in retirement communities for low-density Sunbelt suburbs [93]
- The limited number of Tesla autopilot cases for conventional personal cars. It should also be noted that Tesla is currently only at automation level 2. Tesla's cars require the driver to be hands-off for no more than 30 seconds, and never have their eyes off the road; while level 5 is completely hands-off, and eyes off any road, weather, and traffic conditions [94]
- The most advanced level 2 car currently available is General Motor's SuperCruise that was designed for limited access divided highways and works on 70,000 miles of roads in the U.S. and in good weather [95]

There have been several advances in fleet operations in the past few years. Strong momentum is building behind driverless human transport by robo-taxi and goods movement by robo-delivery and robo-truck. Goods movement autonomy could be categorized into four types: streets, controlled environments, resource roads, and highways. Regarding the automated street movement of goods, for business-to-business (B2B) parcel delivery, Waymo is working with UPS, while GATIK is working with Walmart and Loblaw. Einride is also working with Oatly, Lidl, and Coca-Cola. Also, with regard to automated business-to-consumer (B2C) parcel delivery, Nuru is working with Fry's Food, Kroger, and CVS.

There is a small market for controlled environments, mainly for industrial use and logistics yards, but big OEMs have not invested much in this area. Concerning resource roads (unpaved roads and remote areas), companies such as FPInnovations employ automated trucks for timber-hauling. Ultimately, when it comes to highways, there are several players in both platooning and solo driverless vehicles. In the case of platooning, active startups include Peloton, Locomation, Robotic Research, while active OEMs include Traton Group, Volvo, and Daimler. With regard to solo driverless vehicles, several companies (such as Utobon, Ike, Waymo, tusimple, Embark, Kodiak, Aurora, Ainride, pony.ai, plus.ai, Navistar, Tesla, Volvo, Traton, and Daimler) are working to enable both ramp-to-ramp and dock-to-dock driverless trips.

Although there have been several concerns related to technology, user attitudes, and regulations of CAVs, software safety engineering and software verification and validation (V&V) have been evolving significantly over the past decade [96]. However, there are still some issues that must be solved to encourage the adoption of CASE vehicles more smoothly. In addition, there is regulatory uncertainty regarding distributed decision-making. Finally – but most importantly, users who might buy CASE vehicles have mixed attitudes about them. The unresolved challenges for successful CASE implementation are discussed in the following four sections: technological obstacles, user attitude problems, regulatory challenges, and the formation of smart cities.

G. UNRESOLVED TECHNOLOGICAL OBSTACLES IMPLEMENTATION CHALLENGES FOR EVs

The cost of battery technology, battery life, the number of charging stations, and the charging wait time are among the main concerns regarding fleet electrification [97]. In addition, there would be no fuel tax income created by EVs to invest in mega-scale projects. A survey of 500 fleet managers by Deloitte [41] found that 86% of users aimed to deploy EVs over the next five years, and that 27% were already utilizing EVs. Just over half (55%) of the respondents cited the high purchase cost of the vehicle as the main barrier to adopting EVs. In the U.S., 48% of the participants said they had concerns over battery life. Rising energy costs were identified as the most significant barrier overall, with 72% citing it as their biggest concern.

Additionally, the infrastructure supporting these new electric vehicles is still lacking for the mass market but can provide support for specific commercial use cases based on fleets. Mohamad and Songthaveephol [98] reported that EV sales accounted for less than 1% of the global vehicle sales from 2011 to 2016 and that investment in charging station infrastructure was needed to increase this figure. To increase EV ownership to a level that is comparable to or even preferable to fossil fuel-use car ownership, infrastructure development must be robust [99]. Long lines of EV cars waiting to be recharged is a sign of many EVs on the road, which requires comparable growth in the number of charging stations. In many countries, the investment needed to upgrade a stations' facilities remains a serious obstacle.

However, merely adding more stations does not solve the most significant barrier to charging, which is how long it takes to charge an EV completely. A fuel pump can, on average, fill the fuel tank of a car in about five minutes, whereas it takes about 30 minutes to recharge using a Tesla Supercharger. The wait time problem is greater than the lack of available charging stations, which also causes long queues. Tesla does make a Supercharger that can give a 75-mile charge in just five minutes, but those stations are not yet widespread. Furthermore, even with Tesla Supercharger's relatively rapid speed, it is not compatible with other brands of EVs. Fully charging a non-Tesla EV can take up to 10 hours, which presents a considerable inconvenience to anyone who does not want to add an extra night to a long-distance road trip.

Suggestions to enhance EV adoption include educating citizens about the benefits and implementation of BEVs, expanding EV charging stations, allocating incentives for private investment, and finally, battery swapping. The public awareness of EV benefits should be correspondingly increased through workshops and podcasts for various age groups. Moreover, electric technology demonstrations should be launched. Another possibility is that governments could start the adoption of a "zero emissions policy" for different types of fleets [100]. Regarding the expansion of charging stations, substantial investments in public charging infrastructure points would be key to the success of EV implementation.

The automobile sector needs to be creative in finding revenue and making the business case comparable to other scenarios for the private sector. Different business models should be developed and deployed for each of the above-mentioned potential solutions as the revenues will differ depending on consumers' interaction with the infrastructure.

Governments could also invest in various mobility types and assemble charging stations in low-income districts. Additionally, the presence of super-charging stations on the street network must be improved significantly. Free parking options for EVs would be another incentive to explore. While the growing number of EV owners wait for a substantial improvement in charging infrastructure, battery swapping could enable people to obtain a full charge without waiting in a queue. EVs could drive into a swap-station and have a robot rapidly substitute the drained battery with a fully charged one. Swapping solves several problems presented by current charging practices, with speed being most obvious.

Another notable issue is that converting all passenger cars in the U.S to electric vehicles would consume 28% more power than the country currently produces [101], [102]. Converting California's cars to electric would consume 50% more power than the state produces. So, it is not just about infrastructure for charging; it is about getting more power from somewhere [102].

It is also crucial to note that a large portion of the population cannot afford ridesharing, AVs, or EVs. Furthermore, the majority of EV buses have been deployed in high visibility areas of a city, and not where most of the ridership congregate [49]. City planners should consider this issue and solve it accordingly.

Additionally, with the emerging trends discussed in the introduction, such as population and urbanization growth, shared electric vehicles (EVs) are playing an increasing critical role in the future mobility-on-demand traffic system. There are multiple proposals to enhance the efficiency of the current models. Liang *et al.* [24] suggest joint charging scheduling, order dispatching, and vehicle rebalancing for large-scale shared EV fleet operators. T. Chen, 2016 [25], introduced a framework for optimal routing and charging of an EV fleet for high-efficiency dynamic transit systems while considering energy efficiency and charging price. Korkas *et al.*, 2018 [26], instead of state-of-the-art charging scheduling based on open-loop strategies that rely on initial operating conditions, suggests an approximate dynamic programming feedback-based optimization approach, where the feedback action guarantees uniformity regarding initial operating conditions. Jerbi *et al.*, 2009 [103], have also proposed an "enhanced greedy traffic-aware routing protocol" (GyTAR). This intersection-based geographical routing protocol is competent in detecting robust and optimal routes within urban environments.

H. IMPLEMENTATION CHALLENGES REGARDING AVs

Concerns about vehicle safety have a considerable impact on consumers' perceptions of self-driving vehicles. Almost half (48%) of U.S. consumers believe that fully automated vehicles are unsafe. A recent study by Deloitte [41] shows that 47% of U.S. citizens in 2018 believed AVs were not a safe mode of travel, with similar figures of 50% in 2019, and 48% in 2020. The AV impact analysis is still at a preparatory stage and is dealing with several ambiguities.

In September 2017, USDOT and NHTSA released the updated *Voluntary Guidance – Automated Driving Systems 2.0: A Vision for Safety*, which includes a recommendation that entities involved in the testing and deployment of automated driving systems provide an assessment of how they are addressing safety to the public. NHTSA safety elements include: system safety, operational design domain, object and event detection and response, fallback (minimum risk condition), validation methods, human-machine interface, vehicle cybersecurity, crashworthiness, post-crash ADS behavior, data recording, consumer education and training, and federal, state, & local Laws. A group of players such as OEMs, MaaS companies, software developers, and freight companies have also published their own *Voluntary Safety Self-Assessment Report (VSSA)*.

With regard to OEMs, Mercedes-Benz [104] and Bosch are working together to advance the development of driverless cars. The BMW [105] Group is also working on its Vision iNEXT, combining ground-breaking design with the future areas of activity defined in the company's strategy. Ford [106] meanwhile has partnered with ARGO AI to deploy a training program for safety operators.

Several companies are developing new safety protocols. Toyota's [107] fundamentals of automated technology include perception (perception combines information from the localization and mapping system with data from vehicle sensors), prediction (prediction helps the vehicle imagine where other vehicles, pedestrians and bicycles. are likely to be in the future) and planning (planning determines one or more safe courses of travel for the vehicle). Waymo's system safety program addresses five distinct safety areas: behavioral safety, functional safety, crash safety, operational safety, and non-collision safety.

Concerning MaaS companies, Uber's [108] approach to safety has been governed by its safety principles. It creates the context for two essential components: the safety case framework for self-driving, and the organizational approach to safety management. Moreover. Lyft [109] has formed a partnership with Aptiv to combine Aptiv's autonomous vehicles with Lyft's network. Zoox [110], Apple [111], Aurora [112], NAVYA [113] and NVIDIA [114] have also been developing platforms that monitor, manage, and optimize operations of automated vehicles. Olli [115] is the first co-created and 3D-printed, self-driving shuttle equipped with cognitive response technology and an obstacle avoidance system. Regarding transporting goods and groceries, Nuru [116] and Robomart [117] are the pioneers of developing fully self-driving, on-road vehicles.

In the area of freight automation, several companies, including Tusimple [118], IKE [119], Kodiak [120], and Starsky Robotics [121], have been working on related issues. Starsky is designing a deterministic automation system that utilizes a human-in-the-loop for specific decision-making processes and completes off-highway segments of long-haul trucking routes by exercising direct remote control over commercial motor vehicles (CMVs) via telemetry. Kodiak Driver has been working to have trucks drive safely and efficiently from highway entrance to highway exit (the middle mile, plus the limited frontage roads it needs to drive to reach a truck port).

Although lane-changing characteristics have been captured by current algorithms, more experience-based information is still required to properly calibrate these models. There are still a number of hardware and software issues along with reasoning errors that face AV implementation. Currently, 88% of ADAS customers are satisfied with the technology. This type of AV technology then can serve as a bridge to build widespread trust and ADAS characteristics have the potential to be viewed as steps to level 5 automation [58]. Continuing to develop ADAS technology will provide a path forward to the realization of a fully AV-penetrated traffic network.

Market research institutes such as TechNavio [122] have predicted that the ADAS market will show a compound annual growth rate (CAGR) of 22% between 2017 and 2022 – an increase equal to nearly $48 billion worldwide. Such functions could help build the backbone of AVs and transform the way in which people drive. Still, a set of regulated driving features regarding smart mobility is necessary for any prospective investigations. Ultimately, the government should strive to educate citizens about the automated technologies for vehicles and the ways in which CASE technologies can alleviate their problems.

This study suggests that stakeholders could further employ gamification and augmented reality to explore the AV for periods when a driver is not required, and on autonomous buses for passenger education or entertainment. Moreover, the AVs' customer input should be investigated to identify what do they like, dislike, and when and why a problem is experienced.

It is also important to note that infrastructure readiness is vital for implementation of automated traffic, particularly the role that signs and road markings play in successfully deploying automated driving systems. The prominence of readability of road markings and road signs for ADAS systems cannot be undervalued. There have been notable signs of progress in organizations such as the European Road Federation, that approved 3rd Mobility Package in 2018 including General Safety Regulation (GSR) [123] calling for ADAS equipped vehicles by 2022-2024 and the Road Infrastructure Safety Management RISM) Directive, which calls for an improved and well-maintained road infrastructure. In terms of standardization of road signs, EU Construction Products Regulation (CPR) [124] CEN TC 226 about traffic signs, passive safety, and road adaptation to CAVs, the UN ECE Land Transport WP1 about updating the Convention on Road Signs and Signals, and the creation of a digitized database are among the efforts that have been made to harmonize road signs and markings better and make them more easily readable by vehicle sensors.

However, there are still several obstacles preventing sensors from reading different types of signs and markings accurately. Traffic authorities need to make road markings more uniform and harmonized, as well as clear, easy, and simple to read. Essential to this is that road authorities frequently replace outdated roadside equipment and prioritize this when calculating their often meager budgets. According to research by the National League of Cities [125], several infrastructure limitations currently exist. Only six percent of the U.S.'s largest cities' transportation plans accommodate any language on the potential impact of CAVs on the mobility network. In many areas of U.S. states, only some parts of the roads are paved and marked well enough for an AV to navigate. Policymakers should invest in machine vision and necessary infrastructure to enhance all roadways and improve the maintenance of infrastructure.

I. IMPLEMENTATION CHALLENGES REGARDING CVs

For the gains brought by CV technology to come to fruition, approximately 80% of vehicles should support signal phase and time (SPAT) information. Certain factors influence the efficacy of connected vehicle systems, including cellular coverage, the number of vehicles equipped with DSRC, and the presence of additional ITS facilities. Most importantly, trust must be built between data owners and vehicle users in order to persuade additional customers to adopt this technology. Concerns about connectivity, privacy, and data security remain a significant implementation challenge. Consumers are divided on whether the benefits of increased connectivity in their vehicles are worth the security issues. They are cautious about whom they can entrust with the data collected and shared by vehicles, and they do not necessarily view the original equipment manufacturers (OEMs) as the most rational choice.

Policies that could increase trust among users should first identified. Openness and accuracy are essential to earning the trust of both the public and regulators. Employing developing technologies such as blockchain could play a vital role in satisfying the demand for transparency and drive the change towards a fully connected infrastructure.

To increase the number of DSRC-equipped vehicles, authorities could use incentives to equip those commercial and government vehicles that have a significant presence on city streets – comprising more than 25% of the traffic – with emerging technologies. USDOT [73] reported that the number of vehicles in use is as follows:

- Government – 3,150,000
- Business – 3,025,000
- Police – 212,000
- Unassigned – 2,709,000
- Utilities – 815,000
- Rental – 2,738,000

Taxis, commercial, and government vehicles are therefore an appropriate starting point for increasing the market penetration and familiarizing people with CASE vehicle technologies. They can help to build trust and, more importantly, encourage a culture of shared-mobility transport. Ultimately, the 5G technology for vehicle-to-infrastructure (V2I) systems must be tested and compared with DSRC regarding reciprocal safety messages.

There have been many signs of progress in vehicle communications and AI development in the field of CVs. Several studies have been conducted on issues such as enhancing the CACC's communication vulnerabilities and impairments such as packet loss and latency. Ploeg *et al.*, 2015 [126], introduce a control strategy for graceful degradation of one-vehicle look-ahead CACC, based on determining the preceding vehicle's acceleration utilizing onboard sensors. To handle the inevitable communication losses, Harfouch *et al.*, 2018 [127], have formulated a comprehensive average dwell-time framework and designed an adaptive switched control strategy. Ultimately, Xing *et al.*, 2019 [128], have also applied the Smith predictor and proposed a control scheme to compensate for the communication delays in a CACC Systems.

There is a need to move from reactive to preventative safety. ADAS systems currently react to road, weather or traffic conditions, and all AVs' sensors capture movement, changes, intersecting threats and react to avoid them. Various stakeholders must collaborate and invest in proactive machine intelligence technologies to process the information so that the vehicle can know in advance of a potential problem and threat and can preventatively adjust speed, course, and trajectory well in advance of the specific problem location.

J. UNRESOLVED IMPLEMENTATION ISSUES ABOUT SHARED AUTOMATED VEHICLES

The advantages offered by new CASE technologies are not a guarantee that users will employ them. Driving a vehicle is often viewed as a representation of independence and in the U.S. in particular, users may resist any change to the norm and the majority of drivers might not be willing to surrender their driver-driven and personal cars. Current vehicle standards, however, are leading to an increase in personal car ownership and have adverse social, environmental, and financial influences on the traffic network. All else being equal, there may be a more rapid uptake in countries with a less entrenched automobile culture.

Several essential factors are at play that could lead to an ideal situation and close the current gaps that hinder the development and deployment of shared mobility. Policies about data-sharing and seamless connectivity between devices and services would enable organizations in the mobility domain to gain insight into users' habits. This could result in precise forecasts of demand and tailored offerings, turning SAV into a "one-stop-shop" for mobility as a service (MaaS) offering. The consumer mindset could then shift from an asset-focused to a digitally focused, asset-free environment, which would boost MaaS. Hence, car owners' and companies' demands could then be addressed to tailor MaaS for each individual.

Despite the recent growth in research on MaaS in passenger vehicle transportation, these subjects have been overlooked in trucking transportation [129]. Monios and Bergqvist [129] have established the chief characteristics of the trucking transportation network and derived a spectrum of possible business models, including the changing roles of the stakeholders. The dignity of ownership would be subsumed by pride in the performance of a system, which would offer complete freedom to the customer, who can then move independently between points.

Organizations in the mobility sector should also design offerings for customers who still desire the same comforts they have always enjoyed by offering them customized and specialized packages. These solutions may include dedicated assets for use on demand, providing the luxury of asset ownership while decreasing personal responsibility and risk. This in combination with government engaging and educating citizens on the benefits of these technologies should also incentivize alternative transportation [130] and [131]. Merfeld *et al.* [132] investigated the driving factors, challenges, and future improvements of carsharing with SAVs. Technology, encompassing functionality, and convenience were identified as the most influential parameters. Moreover, economic drivers, such as demand and supply parameters, got high ratings.

K. UNRESOLVED USER ATTITUDE PROBLEMS

If people do not want to utilize new automobile technologies, they ultimately will not succeed. Currently, attitudes range from irrational exuberance to adamant hostility about the adoption of CAVs. The barriers to CASE implementation have recently gained further clarity. Factors that hinder growth and the adoption rate of CASE vehicles are users' cognitive bias against new automobile technologies, safety and trust issues, and the costs of adopting new technologies. Liu and Xu [133] conducted field research to investigate the impact of direct driving experience on attitude change toward CAVs on the public roads. They identified that direct experience persuades ambivalent drivers to be more positive. They also recommend that policymakers and automakers give opportunities for public drivers to test CAVs to form positive opinions.

One reason that citizens might not accept new technology easily is because of a cognitive bias. The fear of loss, for example, can appear to be more likely than the possibility of reward. Additionally, users tend to place value on items they already possess, leading to a greater appreciation of their traditional vehicles over SAVs. Both of these biases could impede the adoption of CASE vehicles. Furthermore, users view SAVs as more dangerous than they are actually reported to be, and they overestimate the odds of certain events such as crashes and cyber-attacks. The limited number of Uber and Tesla's crashes have shaken public confidence, and any more could be devastating. It is inevitable that AVs will cause crashes, and people will be injured or killed because of the unpredictability of the driving environment. However, it is expected that deaths would be less than 10% of those currently attributed to human drivers [134]. Deloitte (2018) [53] states that safety and brand trust are critical factors that determine the consumers' acceptance of CAV technologies and the prime reason for an individual to be dubious about adopting technology is a lack of trust in it [57]. Trust is not given but earned over the long term and individuals must accept the technology as being safe, secure, and reliable.

Therefore, the replacement of personally driven vehicles for CASE vehicles may take longer than initial predictions. Behavioral interventions must be implemented to help governors overcome these cognitive barriers among citizens regarding adoption.

Since most consumers exaggerate the losses of replacing traditional vehicles relative to the benefits, advocates need to instead highlight the potential losses of not selecting a CASE vehicle. In the same vein, rather than advertising the adoption of CASE vehicles, advocates should present what not buying CASE vehicles could result in. To overcome skewed judgments about loss and risk, companies could also investigate expanding the appropriate timeframe or pooling the costs, informing citizens of the odds of being in a crash or the cost of employing these vehicles over 50 years in comparison with single-trip statistics. Advocates of SAVs would be wise to highlight the average time that would be gained annually by using CASE vehicles, not the few minutes gained daily. Authors also believe that we will have a mixed fleet (AV and non-AV) fleet for a long time and people may be wary of sharing road space with AVs and vice versa.

L. UNRESOLVED CASE VEHICLE REGULATORY CHALLENGES

As mentioned, concerns about privacy and data security regarding CASE-vehicle technologies currently prevail. CASE vehicles will run on complex, high-level onboard computing systems that will have the capacity to convey large quantities of data about consumers and their locations to third parties. Concerns will arise as market penetration increases and data distribution becomes commonplace [135]. Transportation decision-makers, auto manufacturers, and future CASE-vehicle users may have concerns as to the adequacy of system security. The consequences of implementing inadequate security for a CAV system are many and may make CASE-vehicles far less alluring to stakeholders.

Other unresolved issues mentioned before include the potential need for an additional license for an AV and the fact that the visual and sensing performance of AVs in harsh weather has not yet been verified. There is also an argument about the liability of CAVs in the event of a crash involving striking a pedestrian or colliding with another CAV. It is not yet known who will be held responsible for this damage and loss of life.

It is generally agreed that for the fruitful adoption of CASE vehicles, product offerors, customers, and the legal system should develop a set of policies considering the social, legal, and ethical concerns, including evaluating their consequences. There should be a delicate balance between protecting the public from unsafe, immature systems, and promising innovations. Additionally, Crayton and Meier [136] provide a framework that could be employed as a foundation for public health partnerships in CASE policymaking.

There is also no coherent and uniform structure in place to obtain permission to test CASE vehicles and this acts as a hurdle to CASE vehicle producers. They are confronted with vast governing ambiguity in different states [21], resulting in increased production costs. Federal and state responsibilities must be overlapped because automation does not fit neatly into the current framework. The legislation will then need to meet both industry and traffic-safety advocates' needs. There is a desire for consistent state-wide standards for the employment of CASE vehicles. While the national government would control the implementation of the required vehicle technologies, the states would be responsible for regulating the day-to-day operation on public roadways. The USDOT NHTSA has been pursuing the formulation of rules mandating new cars to be equipped with DSRC connectivity; however, the mandate has been on hold since a change in the U.S. administration in 2017 [136]. The potential for adoption of these regulations is currently unknown. If adopted, there may be broad implications for the operation of the entire surface-transportation system. However, the recent NPRM issued by FCC regarding the 5.9 GHz band has added another layer of uncertainty regarding the future path to the large-scale deployment of CVs (FCC).

To address privacy-related concerns, safeguarding actions can be used to shield the vehicles' information stream. A critical component is designing policies that make any data misuse illegal. It is essential to note that a standard cell phone user already gives up significantly more information about himself or herself such as location, travel information, purchase information, etc. In comparison, the privacy concerns of CASE vehicles would be minimal. Concerning insurance and liability, CAVs need to utilize the advanced technology to improve their ability to make reliable choices more rapidly. Existing tort law already completely covers AVs. Those piloting the vehicle are liable and if machine intelligence is piloting it then liability is on the OEM and its suppliers [136].

M. UNRESOLVED PUBLIC FUNDING IMPACT OF CASE VEHICLES

Scholars should also consider in depth the public funding impact of CASE vehicles and find ways to pay for this system transition. Most public agency revenues come from the fossil fuel-powered, manually driven, and privately owned model; CASE vehicles eliminate all these revenue sources of sales and gas tax, parking fees, and speeding fines. It is critical to consider that the new digital governance model will need a new financing mechanism to pay for the transition. A combination of pricing mechanisms that include VMT, weight, and curb pick-up and drop-off, including other fees, will be necessary to fund, repair, and maintain the public right of way. Pricing does two things. It provides revenues for maintenance and provides mode shift incentives to more sustainable modes, from higher occupancy to lower space footprint modes (walking, bicycling and scooters) that will be key to the success of the transition.

V. CONCLUSION

The subject of connected, automated, shared, and electrical vehicles is a multidisciplinary issue with several stakeholders engaged in their implementation. There are several teams, from federal and state agencies, OEMs and academia, to startups and larger consortiums, working on this complex subject. This study investigated several academic papers, as well as federal and industry reports, considering all the stakeholders mentioned above, to present a comprehensive picture of both the drivers and the barriers to implementation of CASE vehicles, and to outline the next steps that stakeholders should consider to overcome those obstacles.

User attitudes and lack of market demand for CASE vehicles, insurance and liability challenges, regulatory issues, infrastructure needs, and technological challenges, are among the significant hurdles identified. To overcome these social and technological concerns, states should shift to creating a more productive, sustainable, and smart environment. The transition from conventional vehicles to CASE vehicles depends on the development of technology as well as consumer acceptance and policies. This research explores the implementation hurdles to using CASE vehicles and presents ideas and provides recommendations to resolve them.

First, concerning unresolved technological obstacles, there are several factors for EVs, AVs, CVs and SAVs that currently require more attention. The high cost of battery technology, short battery life, the limited number of charging stations, and the long wait times for charging, are among the biggest concerns for fleet electrification that researchers must solve. Regarding AVs, most ADAS users are satisfied with the technology, and the main stakeholders must, therefore, better present this automated technology to gain consumers' trust. Regarding CVs, specific determinants impact the effectiveness of these systems, including the number of DSRC-equipped cars, the cellular coverage quality, and the presence of additional ITS facilities. Currently, for SAVs, most citizens view car ownership and driving as symbols of freedom and prestige and the user mindset must change from an asset-focused environment to a digitally focused and asset-less environment that supports mobility as a service (MaaS).

Second, there exists a significant gap between car owners, companies, and public parties and their willingness to accept and pay for the new CASE technologies. Moreover, there are still trust issues and critical doubts about the safety and costs of these vehicles. Policymakers need to better identify potential policies that can increase the level of trust among users.

Third, concerning unresolved regulatory challenges, issues such as privacy and security, licensing, and insurance and liability are among the main factors that still need further investigation. All stakeholders in the regulatory environment – whether federal, state, or local – must work together and pass the required laws needed for the smooth implementation of CASE vehicles.

The conclusions of this study have shown that various barriers are in place that impede the implementation of CASE vehicles on the roads. Despite this, there is a collaboration gap between the main stakeholders, namely technological companies, federal and state agencies, and human drivers. These principal stakeholders need to work together to tackling the obstacles to implementing these upcoming technologies. By considering the influences examined in this work and removing the barriers to implementation and adoption of CASE vehicles, the government can then leverage the benefits of these vehicles. By so doing, the roads' level of service will ultimately be enhanced.

ACKNOWLEDGMENT

The authors would like to show our gratitude to Mr. Richard Bishop for assisting us during this research.

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AMIRSAMAN MAHDAVIAN (Graduate Student Member, IEEE) received the B.Sc. degree in civil engineering from Amir Kabir University (the Poly-Technic of Tehran), and the Ph.D. degree in transportation management from the University of Central Florida (UCF). He then worked in Transportation and Construction projects in the industry for four years. He received several honors for his contributions including at UCF. He is currently a main part of the Smart Mobility and ACES Vehicles Research Group, UCF.

ALIREZA SHOJAEI joined as an Assistant Professor with the Building Construction Science Department, Mississippi State University, in 2018. His research program is focused on computer-based modeling and simulation. His current research interests include digital innovation and the application of emerging technologies in the built environment and project management and economics in the construction industry. His track record of publications and grant proposals include information modeling, data sensing and analytics, machine learning, and smart design and construction.

SCOTT MCCORMICK received the degrees in mathematics, mechanical, and aerospace engineering, the master's degree in business administration, and the Ph.D. degree in artificial intelligence. Prior to being the President of the Connected Vehicle Trade Association (CVTA), he was the Executive Director of the Automotive Multimedia Interface Collaboration, a nonprofit research organization of the world's largest automakers. In March 2012, and again in 2014 and 2016, he was appointed by the United States Congress to advise the Secretary of Transportation on matters relating to the study, development, and implementation of Intelligent Transportation Systems. In 2016, he was named the Chief Transportation Consultant to the Asia Pacific Region by the U.S. State Department. In June 2016, he was inducted into the TU Automotive Hall of Fame, Detroit, MI, USA.

TIMOTHY PAPANDREOU is currently a Founder Emerging Transport Advisors: provide guidance, mentoring, training, and market landscape expertise to global investors, companies, startups (all stages), governments (all levels), and institutions to successfully harness and get smarter about the shared, electric, and automated mobility opportunities. He is also a former Google X and Waymo strategic partnerships to deliver First-in-kind bets, commercialize Waymo and launch the world's first fully self-driving ride hailing service. He is also a Co-Founding Advisor to City Innovate's Start Up in Residence urban mobility program with more than 50 cities. He is also the former Chief Innovation Officer San Francisco MTA. He pioneering expert on all modes of transport (people and things), working with cross-functional teams to develop the vision, policy, go-to-market launch, and scale.

NAVEEN ELURU is currently an Associate Professor with the Department of Civil, Environmental, and Construction Engineering, University of Central Florida. His research interests include primarily geared towards the formulation and development of discrete choice models that allow us to better understand the behavioral patterns involved in various decision processes. He has conducted research on several topics including transportation planning, transportation safety, land-use modeling, integrated demand supply models, public health, and environmental sciences. He has published extensively in premier transportation safety journals, such as *Accident Analysis and Prevention* and *Analytic Methods in Accident Research*.

AMR A. OLOUFA is currently a Professor and the Director of Construction Management with the University of Central Florida. He has a long history of substantial contributions in transportation and construction research and education and has served in many leadership capacities, as evidenced by his role, among others, as the Editorial Board of 20 journal articles. His primary expertise and interests include in the areas of traffic analysis, truck diversion, software development, simulation, big data, data analytics, and ITS. He has managed 19 transportation management related projects with funding in excess of $6 million supported mostly by FDOT and CATSS. He led the team to complete this comprehensive literature review article.