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Socioeconomic Impacts of Automated and Connected Vehicles

Summary of the Sixth EU–U.S. Transportation Research Symposium

Andrea Ricci
Rapporteur

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Acronyms

AV	automated vehicle
CAV	connected and automated vehicle
CAVSM	connected and automated vehicles and shared mobility
CV	connected vehicle
EU	European Union
EV	electric vehicle
ISINNOVA	Institute of Studies for the Integration of Systems
lidar	light detecting and ranging
NASEM	National Academies of Sciences, Engineering, and Medicine
PPP	public–private partnership
TRB	Transportation Research Board

Preface

This document summarizes Socioeconomic Impacts of Automated and Connected Vehicles, a symposium held June 26–27, 2018, at the Hotel NH Brussels Bloom in Brussels, Belgium. Hosted by the European Commission and the Transportation Research Board (TRB) of the National Academies of Sciences, Engineering, and Medicine (the Academies), it was the sixth annual symposium sponsored by the European Commission and the United States. The goals of these symposia are to promote common understanding, efficiencies, and trans-Atlantic cooperation within the international transportation research community while accelerating transport-sector innovation in the European Union and the United States.

The 2-day invitation-only symposium brought together high-level experts to share their views on the socioeconomic impacts of connected and automated vehicles and shared mobility (CAVSM). With the aim of fostering trans-Atlantic collaboration in research and deployment, symposium participants discussed challenges and opportunities arising from the diffusion of CAVSM and innovative approaches to mitigate any negative socioeconomic impacts.

A bilateral planning committee was jointly assembled by the European Commission and TRB to organize and develop the symposium program. Barbara Lenz of the German Aerospace Center and Susan Shaheen of the University of California, Berkeley served as cochairs of the planning committee. Committee members provided expertise in innovative mobility systems and solutions, economics and welfare, safety and security, privacy and data protection, land use and transport planning, and equity issues.

The planning committee was responsible for organizing the symposium, identifying speakers, commissioning a white paper and developing four exploratory topic papers to facilitate discussion at the symposium. The white paper is provided in Appendix A and the exploratory topic papers are presented in Appendix B. Readers may find it advantageous to review the white paper and the exploratory topic papers first to better and more fully understand the discussion in the breakout groups.

The exploratory topic papers address how CAVSM affects people in the freight sector and its impact on the places where people live, work, and play; on travel behavior; and on the role and attitude of stakeholders involved. The papers were developed and presented by planning committee members to help frame the discussions in the breakout sessions, which focused on formulating problem statements and subsequently identifying research topics appropriate for EU-U.S. collaboration.

The symposium format allowed for continuing interaction and gathering ongoing inputs from the participating experts. The white paper prepared for the symposium was presented in the opening session by coauthors Johanna Zmud of the Texas A&M Transportation Institute and Nick Reed of Bosch. Karel Martens of the Israel Institute of Technology, and Michael Ableson of General Motors discussed equity issues arising from CAVSM and developing fair transportation systems in the automated and connected era.

The breakout sessions followed a common format, building on introductory presentations by the planning committee members, which highlighted the key elements of the exploratory papers. The participants then discussed challenges, opportunities, and areas of potential research that were presented by the planning committee members in the closing plenary session, along with targeted comments and testimonies from participating experts. Concluding comments were also offered by European Commission and TRB representatives.

This report was prepared by the symposium rapporteur, Andrea Ricci, of the Institute of Studies for the Integration of Systems (ISINNOVA), Rome, Italy. The report features a compilation of the presentations and a factual summary of the ensuing discussions at the event, followed by EU-U.S. potential research topics on the socioeconomic impacts of CAVSM. The planning committee was responsible solely for organizing the conference, identifying speakers, developing exploratory topics, and moderating the breakout sessions. The views expressed in the report are those of individual experts attending the symposium and do not necessarily represent those of all participants; the planning committee; TRB; the Academies; or the European Commission.

This summary was reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise in accordance with procedures approved by a Report Review Committee consisting of members of the Academies. The purposes of this independent review are to provide candid and critical comments that will assist the institution in making the published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the project charge. The review comments and draft manuscript remain confidential to protect the integrity of the process. TRB thanks the following individuals for their review of this summary: Randy Iwasaki, Contra Costa Transportation Authority; Tina Quigley, Regional Transportation Commission of Southern Nevada; and Susan Shaheen, Transportation Sustainability Research Center, University of California, Berkeley.

Although the reviewers listed above provided many constructive comments and suggestions, they did not see the final draft of the proceedings before its release. The review of this proceedings was overseen by Susan Hanson of Clark University (emerita). Appointed by the Academies, she was responsible for making certain that an independent examination of this proceedings was performed in accordance with established procedures and that all review comments were carefully considered. Responsibility for the final content rests entirely with the authors and the institution. The conference planning committee thanks Andrea Ricci for his work in preparing this conference proceedings.

Opening Session

Clara de la Torre, *Directorate-General for Research and Innovation, European Commission, Brussels, Belgium*
Robert Missen, *Directorate-General for Mobility and Transport, European Commission, Brussels, Belgium*
Neil J. Pedersen, *Transportation Research Board, Washington, D.C., USA*
Alasdair Cain, *U.S. Department of Transportation, Washington, D.C., USA*
Barbara Lenz, *Institute of Transport Research, German Aerospace Center, Berlin, Germany*
Susan Shaheen, *Transportation Sustainability Research Center, University of California, Berkeley, USA*
Nick Reed, *Bosch, United Kingdom*
Johanna P. Zmud, *Texas A&M Transportation Institute, USA*
Karel Martens, *Technion—Israel Institute of Technology, Israel*
Michael F. Ableson, *General Motors LLC, USA*

Welcome from the European Commission

Clara de la Torre and Robert Missen

Clara de la Torre welcomed all participants and thanked the members of the planning committee for their hard work in organizing the symposium, the authors of the white paper, the speakers for sharing their knowledge and insights, and the participants for making time for this event in their busy schedules.

She reviewed the history of the collaborative EU-U.S. symposia, stressing that the success of the first series of four had prompted a second series. Since 2013, the symposia have in fact proved an excellent method for sharing information on critical issues, best practices, and research gaps. Initial promising outcomes from the symposia have included early learning, expanded networking, and collaborative research opportunities. The symposia thus succeeded in fostering greater trans-Atlantic interaction between researchers and practitioners, notably through the twinning research approach,[1] which supports the European Union and the U.S. Department of Transportation in issuing separate but compatible calls for research.

Coming to the specific topic of this sixth symposium, De la Torre emphasized the importance of examining the socioeconomic impacts of automated and connected vehicles (CAVs) on the transport system. Over the coming decades, the reach of CAVs may surpass what stakeholders already consider a driver of transformative change in the sector. It is therefore essential to explore the degree to which connected and automated vehicles and shared mobility (CAVSM) may prove beneficial or adverse in achieving common societal and economic goals.

De la Torre noted that progress in the technologies and innovative business models for CAVs proceeds at a fast pace, while old and new questions over the potential for significant socioeconomic impacts in the long-term are yet largely unanswered. High-level automation, increasingly connected systems, and a far broader interface between the consumption and the provision of transportation services will not succeed at scale merely by integrating more and better technologies. Considering the importance of ensuring the buy-in of citizens for these new technologies and of achieving a better understanding of how transport users and society at large perceive and value their future use, de la Torre pointed to the need for more research and innovation to assess the impacts, benefits, and costs of the deployment of CAVSM

[1] Twinning: coordination of research activities in funded projects of mutual interest.

on our roads. She reviewed the multidisciplinary nature of CAVSM development, which embraces transport planning, design, operations, finance, economics, insurance, risk assessment, risk balance management, public outreach, and public policy. De la Torre also invited participants to adopt a cross-modal perspective in their discussions.

De la Torre concluded by highlighting noteworthy features of Horizon Europe, the forthcoming EU framework program for research and innovation (2021–2027), whose overarching goals are to strengthen the EU's scientific and technological base; boost Europe's innovation capacity, competitiveness, and jobs; and deliver on citizens' priorities. She notably mentioned that in its "Pillar II: Global Challenges & Industrial Competitiveness," Horizon Europe will invest around 15 billion euros (US$17.5 billion) in the Climate, Energy, and Mobility cluster, including interventions to boost industrial competitiveness in transport, promote smart and clean mobility, and, possibly, a public–private partnership (PPP) on CAVs. International cooperation will likely be enhanced with intensified targeted actions and through full openness to researchers across the world.

Robert Missen stressed the importance of providing sufficient knowledge to policymakers engaged in the development of CAVSM. He stressed that understanding and assessing socioeconomic impacts, often called the soft side, is no less critical than harnessing technological progress, and he shared his expectations that the symposium would explicitly contribute to this goal through comprehensive and targeted discussions.

Welcome from the Transportation Research Board

Neil J. Pedersen

Neil Pedersen reviewed the past experience of the EU-U.S. symposia and praised their concrete usefulness in generating new research and enabling a mutual learning process between the European Union and the United States. Pedersen particularly welcomed the topic of this sixth symposium, which aims at stimulating novel research and the generation of new knowledge on the socioeconomic dimension of CAVSM. He stressed that the technology options for CAVSM are broadly identified, while their social and economic implications are largely understudied. He noted that the symposium participants can contribute to a better understanding of socioeconomic impacts, not only in their expert capacity but also as citizens and consumers.

Pedersen stressed the importance of equity issues, the implications of CAVSM, and the need to better understand if and to what extent technology can respond to equity goals and concerns. He also remarked upon the high relevance of demographic variables in assessing the social and economic impacts of CAVSM, including geographic mobility of people.

Among other key implications of CAVSM, Pedersen stressed privacy issues and the manifold challenges of handling personal information while safeguarding the rights of individuals to preserve their privacy. Overall, the diffusion of CAVSM calls for a governance structure and rules that pay due attention to their socioeconomic dimension.

Pedersen finally cautioned against the speculative thinking that too often accompanies socioeconomic implications of novel technologies and solutions. These should be assessed on the basis of solid scientific evidence; hence the need to devise appropriate research programs that explicitly address the socioeconomic dimension.

Welcome from the U.S. Department of Transportation

Alasdair Cain

Alasdair Cain thanked the symposium organizers and all participants, stating that such a gathering of the best experts from both the European Union and the United States ensures that the contribution of the discussions will make the CAVSM transition happen in the safest manner. He noted that the novel solutions brought in by CAVSM will generate impacts for the coming decades and thus call for a carefully designed, long-term-oriented research effort.

Cain remarked that the nature, scope, and scale of CAVSM unquestionably require an effective international coordination framework and targeted instruments. In this regard, the twinning platforms previously established as a result of past symposia have proven their worth and could be further pursued.

Cain praised the high quality of the symposia reports so far, as this is the basic prerequisite for translating scientific evidence into policy.

Purpose and Scope of the Symposium

Barbara Lenz and Susan Shaheen

Barbara Lenz and Susan Shaheen, the symposium cochairs, introduced the members of the planning committee and thanked them for their dedication throughout the symposium preparation process. They presented the thematic allocation of responsibilities between members and praised the team spirit that developed within the committee.

Lenz and Shaheen noted that at a time of great disruption and uncertainty, there is a need to understand cross-

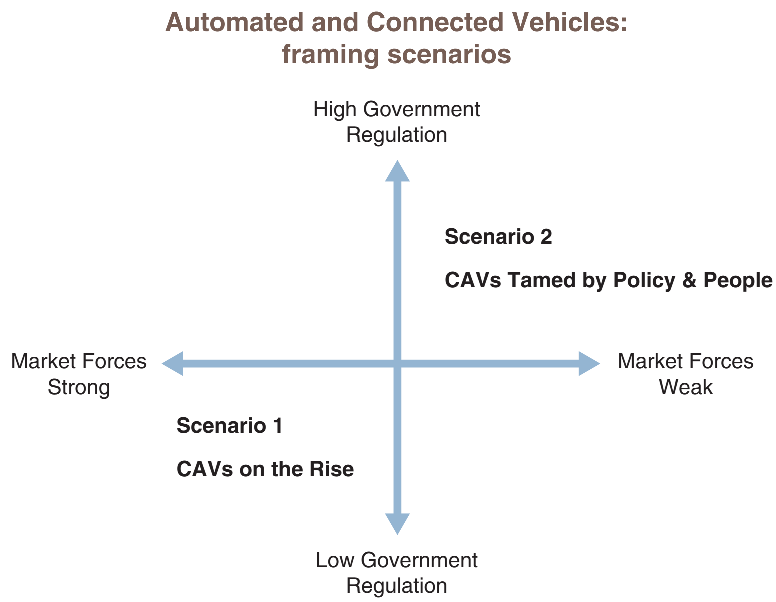

FIGURE 1 Framing scenarios for CAVs.

cutting impacts of CAVSM and devise joint research programs to explore them. To this end, the symposium was designed to identify similarities and key differences between Europe and the United States and, accordingly, to develop potential research topics to address them.

Academia, government, industry, and public interests are increasingly developing a collective narrative on CAVs and shared forms of transport. The main motivation of the symposium was, therefore, to explore how CAVSM may prove beneficial or not in achieving common societal, environmental, and economic goals and to identify pathways that will mitigate unintended consequences.

Lenz and Shaheen summarized the methodology adopted to make the most of the symposium discussions. Four topics were identified—freight transport; places where people work, live, and play; people's behavior; and stakeholders' role and attitude—and the specific implications of CAVSM for each topic were explored. Four transversal themes were also identified so that each exploratory topic could be examined from the perspectives of economics and welfare, equity, data access and privacy, and safety and security.

The cochairs further presented the two alternative scenarios devised to frame the discussion on the four-by-four structure shown in Figure 1, driven by different combinations of government regulation and market forces. Lenz and Shaheen finally encouraged all participants to share their ideas and experiences in the breakout sessions,[2] which were designed to provide a fundamental contribution to the ultimate symposium outcome of research problem statements, which would then be translated into areas of potential research and joint initiatives.

Presentation of the Symposium White Paper: Synthesis of the Socioeconomic Impacts of Connected and Automated Vehicles and Shared Mobility

Johanna P. Zmud and Nick Reed

Johanna Zmud and Nick Reed presented the white paper they prepared for the symposium, "Synthesis of the Socioeconomic Impacts of Connected and Automated Vehicles and Shared Mobility." The complete text of the white paper is provided in Appendix A. Zmud and Reed's presentation covered the topics summarized below.

Zmud reminded participants that the main objectives of the white paper were to provide foundational, high-level information on socioeconomic implications of CAVSM and to introduce and facilitate the symposium discussions. She noted that CAVs result from the combination of two technological realms: connectivity and automation.

In the United States, automated vehicle (AV) and connected vehicle (CV) systems are viewed as independent technologies, whereas in Europe they are seen as complementary. Significant differences between the European Union and the United States are also found in terms of regulation. Policy and regulations are not prescriptive in the United States, where reliance is rather on voluntary guidelines for the AV industry and best practices for AV testing on public roads. The National Highway

[2] Each breakout group included between 12 and 15 participants (from both the European Union and the United States) representing academia, business, and policy making.

Levels of Automation

Level 0: No automation.
Level 1: Human controls driving, but the automated systems can take over one major driving function, such as steering or speed.
Level 2: Human is responsible for safety-critical functions. Automated systems can execute both steering and acceleration/deceleration functions to assist driver. Most automakers are currently developing vehicles at this level.
Level 3: Vehicle can manage all safety-critical functions under certain conditions, but human is expected to take over driving tasks when alerted.
Level 4: Vehicle is self-driving in some conditions or situations but not all.
Level 5: Car can be completely self-driving in all situations. Requires absolutely no human participation in driving tasks.

Traffic Safety Administration is responsible for vehicle equipment, while states regulate human driver and vehicle operation, and legislation is not harmonized across states. In Europe, on the other hand, the European Commission aims at harmonizing the legal framework along with research and industrial innovation across member states; a first set of use cases (Levels 3–4 for passenger cars and trucks on motorways and cities; Level 4 for public transport in low speed situations) has been identified to help shape policy and regulation.

Zmud discussed the data privacy and access dimension of CAVSM. She remarked that CAV and shared mobility systems have in common the large amount of data they collect. This collection of data entails a potential increase in privacy risk and four types of potential privacy problems for individuals: loss of trust, loss of self-determination, discrimination, and economic loss. These possible problems are dramatically reflected in the results of a 2015 survey carried out in the United States in which 91% of adult respondents agreed that consumers have lost control of how personal information is collected and used by companies. A critical issue in fact arises from who has access to personal/location data and whether these data are directly or indirectly (e.g., in combination with other data) threatening individual privacy. Control of data access is therefore fundamental to prevent misuse or mistreatment of personal data. Zmud noted that protocols for privacy protection and data significantly differ between Europe and the United States. In the United States, the Federal Trade Commission Act of 1914 prohibits unfair or deceptive practice (without, however, specific CAVSM provisions) and while most states have some form of privacy legislation, none address CAVSM data. In the European Union, data privacy is akin to a constitutional right, which has recently materialized in the General Data Protection Regulation that harmonizes regulation across member states.

In discussing safety and security challenges, Zmud remarked that more than 90% of road accidents are caused by human error, which contributes to the high safety expectations associated with AVs. She noted that connectivity also has a promising potential to increase safety, as safety messages could reduce accident severity or prevent traffic crashes. However, the safety benefits of CVs can only be reaped if the vehicle is equipped with the proper applications that are turned on with the driver paying attention. Altogether, safety is the primary motivator for CAVs in the United States, whereas in the European Union, additional benefits are also targeted to the environment and to congestion levels, with vehicle-to-infrastructure technologies playing a fundamental role for smart mobility applications. Zmud then commented on the extent to which CAV technologies are likely to fulfil their safety promise, on the critical importance of testing on public roads, and on the learning effect this can spur: the more AV miles/kilometers are driven, the faster safety improvements are likely to be achieved and, thus, to help build the necessary trust and acceptance, the lack of which is currently a major barrier to adoption (see Figure 2). As for security issues, Zmud observed that cybersecurity is an obvious challenge for CVs but also raises concerns for AVs when they reach Level 4 or 5. Security by design is now recognized as the guiding principle to address CAV security issues from the start.

Reed discussed economics and welfare issues raised by CAVSM. He noted that economic considerations will always be a factor in the development and ultimate success of new technologies. CAVs are no exception, and it is especially important to understand how their economic and welfare effects will be distributed.

Reed remarked that employment costs for professional drivers account for a large share of total operating costs (43% for truck drivers in the United States and as much as 88% for a taxi in Zurich, Switzerland), with AVs thus paving the way to huge potential savings. Additional savings could be achieved on fuels, which account for 20%–25% of operating costs and could be reduced by as much as 8% by truck platooning with CAVs (see Figure 3).

Savings in wages arising from AVs are, however, likely to be at least partially offset by the higher purchasing costs of the additional technology. Altogether, a Price-

Safety and security concerns impact likelihood to use AVs

Rank	Privately Owned AVs	AV Carsharing Fleets[a]	AV Ridesourcing Fleets[b]
1	**Safety** of reaction time	Lack of **information**	**Privacy**
2	**Cost** (purchase)	**Trust** in AV technology	Vehicle **hacked**
3	**No need to own car**	Lack of **control**	**Safety** of reaction time
4	**Like to drive**	**Safety** of reaction time	**Trust**
5	**Cost** (maintenance/repair)	**Safety** of AV not personally owned	Lack of **information**

Source: Texas A&M Transportation Institute
[a]Carsharing offers members access to vehicles by joining an organization that provides and maintains a fleet of cars and/or light trucks. These vehicles may be located within neighborhoods, public transit stations, employment centers, universities, and so forth. The carsharing organization typically provides insurance, gasoline, parking, and maintenance. Members who join a carsharing organization typically pay a fee each time they use a vehicle.
[b]Ridesourcing services are prearranged and on-demand transportation services for compensation in which drivers and passengers connect via digital applications. Digital applications are typically used for booking, electronic payment, and ratings. (Source: SAE International J3163, September 2018, http://sae.org/shared-mobility/.)

FIGURE 2 Safety and security concerns.

waterhouseCoopers study estimated that with the rapid uptake of AVs, transportation costs could be reduced by 30% by 2040.

Reed observed that in an industry that has an aging driver population and struggles to attract new entrants, the advent of automated deliveries may help to mitigate the shortfall of professional drivers in both the United States and Europe. This notwithstanding, the International Transport Forum estimated that by 2030, around two-thirds of the 6.4 million truck driver jobs across the United States and Europe could be eliminated by automation. Reed remarked that this huge job loss could be mitigated by a change in the responsibilities and role of the driver, calling for a different skill set and retraining. He noted that additional savings could be achieved through new vehicle forms that maximize productivity, as, for instance, in short-range urban deliveries.

As for passenger transport, Reed remarked that in areas that are poorly served by public transit systems, AV services may help residents and businesses to meet their mobility needs, which in turn may support citizens into employment and reduce dependence on publicly funded services for transportation and medical care. Improved accessibility may, however, lead to increases in housing prices and a subsequent rebound distancing from education and employment opportunities. Reed also expressed caution about the true extent to which travel time can be successfully reclaimed for productive uses in an AV (for example, people suffering from motion sickness might find it difficult to read or write while traveling in a driverless vehicle).

Reed then noted that a significant benefit of CAVs is how they might facilitate a move toward shared mobility (Figure 4). Research has indicated that one shared AV may replace as many as nine individually owned cars in an urban environment, which is an attractive proposition for congested cities. However, some conflicting evidence is beginning to emerge, with users showing

European Truck Platooning

Source: Volvo

FIGURE 3 European truck platooning.

Self-driving commute?

Source: Rinspeed

FIGURE 4 Depiction of self-driving.

behavioral adaptations that result in increased vehicle miles/kilometers traveled and cannibalization of trips from public transit. City authorities will need to monitor the progression of these behavioral changes carefully and respond appropriately to ensure optimal outcomes.

Reed observed that while a shift toward shared mobility has the potential of significantly reducing the urban space allocated to parking, city authorities are unlikely to welcome the prospect of free-floating vehicles roaming the streets awaiting their next assignment. While the shift toward shared AV operation could indeed have a significant impact on safety, he noted that the most advanced safety systems tend to be made available on high-end vehicles before trickling down to lesser models. As a consequence, it may be many years before these safety systems are present on the vehicles of the riskiest drivers, typically those who are young and not able to afford a new car. Reed therefore commented that safety features and systems that can deliver benefits in the short term should not be overlooked in favor of more distant and yet unproven technologies.

Reed discussed the social equity implications of CAVSM, and their potential to enable communities of citizens to gain greater access to opportunities for employment, education, health, and social interaction. These social benefits are likely to be particularly relevant for travelers with additional needs, such as those who are elderly, persons with disabilities, and those living in areas that are underserved by the existing transport provision. Reed, however, remarked that if city and regional authorities cede responsibility for public transit to private companies operating AVs, there is a risk that operational areas will be selected on the basis of their potential to generate the greatest profit rather than on the goal to maximize mobility for the broadest set of stakeholders.

Reed concluded by observing that the deployment of CAVs is associated with a wide range of interconnected issues, some presenting positive prospects, others raising legitimate concerns. It will be essential to manage interests across the public and private sectors to maximize benefits and ensure their equitable distribution.

Setting the Scene: Designing Fair Transportation Systems

Karel Martens and Michael F. Ableson

Karel Martens discussed the possible role of AVs in ensuring transport justice and elaborated on the general question "Can an autonomous mobility future be a fair future?" He observed that in the past, the role of governments was to invest in infrastructure (considered as public goods). Now, it is recognized that a fundamental duty of governments is to provide sufficient accessibility to all, under virtually all circumstances, to enable freedom of movement. He noted that while the overall accessibility concept is clear, it is difficult to measure, as the term "sufficient" is ambiguous and highly subjective.

Martens observed that significant progress has been made to improve transport conditions and accessibility performances. This progress, however, comes at a cost, as the fruition of new and better transport services is constrained by three main factors: purchase power (affordability), (dis)abilities, and the need to ensure the mobility of children.

Martens developed three possible scenarios for the deployment of CAVSM: In the first scenario, automation is only partially achieved, with no equity benefits being accrued, as the limiting factors remain largely unaddressed (e.g., purchase power, impairments). The second scenario features full automation and the persistence of the private car ownership model, allowing for an accessibility improvement for persons with disabilities and for the transport of children without fully removing the obstacles. In the third scenario, full automation is achieved with shared mobility as a prevailing role, which may be construed as a limitation to the freedom of owning a car while offering a similar impact balance to Scenario 2.

Martens concluded that to ensure the fairness of transport systems, policies should start by considering people and their needs rather than technologies and their performances, because CAVSM, along with other technological innovations, is not a magic wand. Justice is not an impact, but a goal, and the role of government is fundamental to promote and facilitate the adoption of new solutions that meet societal needs and aspirations.

Michael Ableson said that General Motors is committed to developing and promoting technologies that contribute to achieving the "three zeros" policy, which is the ultimate eradication of (1) accidents and their social and economic costs, (2) emissions that endanger the environment and the global climate, and (3) congestion and the huge social burden it imposes upon society. He emphasized the priority assigned to safety issues, particularly for AVs from Level 4 upwards.

He argued that the deployment of AVs is strongly correlated with that of electric vehicles (EVs) and that a major goal to be pursued is to ensure that all AVs are powered by electricity only. He further stressed that the introduction of shared AVs fosters the democratization of automotive technology and accessibility and noted that General Motors is a forerunner in the experimentation of on-demand shared mobility exclusively operated with full EVs, with already more than 150,000 users.

Outlining future prospects, Ableson remarked that the safe and successful deployment of AVs requires considerable investment, in the billions, which is well beyond small-scale experimentation projects. He noted that the cost of AV equipment is currently higher than that of the vehicle itself, as 40% of the vehicle parts are new, and that trials which are carried out in uncontrolled environments are extremely demanding.

The overall high costs of AVs notwithstanding, Ableson argued that full-scale AVs will be available as of 2019, and that the future transport system will most likely see the prevalence of mixed (multipurpose) AVs.

He mentioned that there is a tendency to overestimate short-term impacts while underestimating those in the longer term, and predicted that the currently high costs of AVs are bound to significantly decrease, from $2 to $3 per mile down to less than $1 per mile for EV/AVs.

Ableson concluded that the emphasis on the socioeconomic impacts of CAVs is highly welcomed, as it may allow society to extend the reach of impact evaluation and assessment beyond transportation into other dimensions (e.g., housing, job access).

Presentation of Exploratory Topics and Areas of Suggested Research

Timothy Papandreou, *City Innovate, San Francisco, USA*
Barbara Lenz, *German Aerospace Center, Berlin, Germany*
Alex Karner, *University of Texas, Austin, USA*
Marcin Stepniak, *Polish Academy of Sciences, Warsaw, Poland*
Alexandra Millonig, *AIT Austrian Institute of Technology, Vienna, Austria*
Susan Shaheen, *University of California, Berkeley, USA*
Matthew W. Daus, *Windels Marx Lane and Mittendorf, LLP, New York, USA*
Satu Innamaa, *VTT Technical Research Centre of Finland Ltd., Helsinki, Finland*

This section summarizes the presentation of the exploratory topic papers by the symposium planning committee members. It further highlights the main research topics discussed in the breakout groups, as presented by the planning committee members. The four exploratory topic papers were presented in the plenary session, and their full text is provided in Appendix B. Symposium participants discussed challenges and opportunities and potential areas for future research in breakout groups facilitated by the planning committee members. The presentations and breakout group discussions followed the format of addressing the four cross-cutting areas where the socioeconomic impacts of CAVSM are expected (economics and the workforce, equity, data access and privacy, and safety and security) in each of the two envisaged scenarios. The adopted four-by-four structure allowed each of the four breakout groups to address each of the four cross-cutting impact areas, as illustrated in Figure 5.

The planning committee did not expect the symposium experts to work exclusively with the two proposed scenarios but to view them as a starting point for discussion, which frequently highlighted extremes to provoke a dialogue about research needs. There was no intent to rank or rate the research ideas discussed, nor was there any attempt to prioritize the potential research topics. The planning committee members presented summaries of the breakout group discussions in the final general session.

Exploratory Topic 1
Freight—Impacts on People

Timothy Papandreou and Barbara Lenz

This exploratory topic focused on both long-haul goods transport and urban or regional delivery. The fundamentally different situation for long-haul and urban delivery represents a particularly complex challenge when designing a "world of road automation."

Lenz and Papandreou described the overall impacts on the freight sector of Scenario 1: Automated Vehicles Taking Over Transport Business, which entails a quick adoption of automation and the upgrading of road infrastructure, with most logistic providers relying on automated truck fleets and the automation of supply chains. In this scenario, freight transport is massively shifted on roads, with negative effects on road traffic and subsequent low public acceptance.

Lenz and Papandreou discussed the implications of Scenario 1 on economics and the workforce. They noted that this scenario requires a considerable investment from the state and is likely to negatively affect the competitiveness of small and independent trucking and distribution companies while spurring the rise of oligopolies. Critical issues therefore arise on the capability and willingness of the state to invest in new infrastructure, the societal acceptability of huge public spending for the benefit of a limited group of companies, and the need to devise new business models to provide automation-

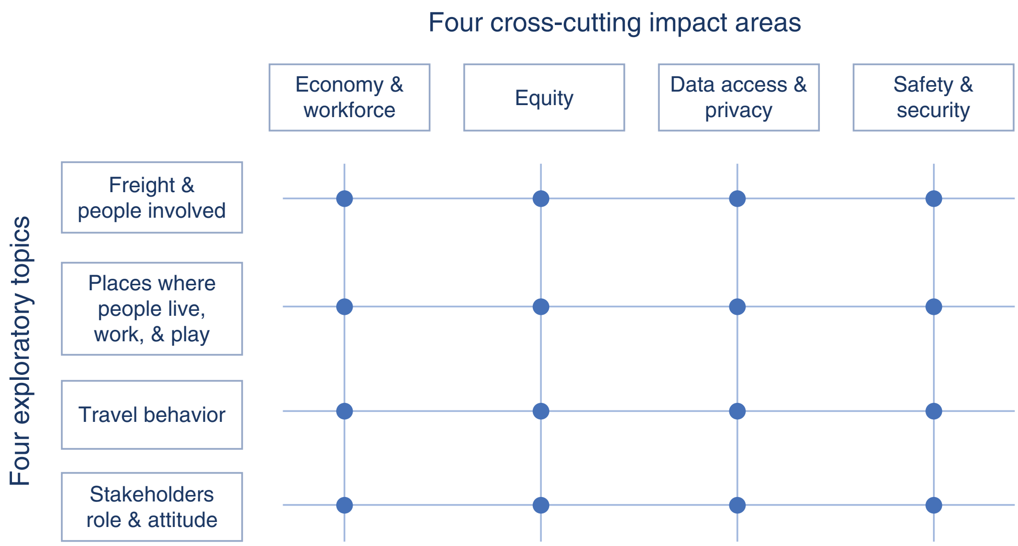

FIGURE 5 Interaction of four exploratory topics and four cross-cutting impact areas.

ready infrastructure requiring motorway tolls. Lenz and Papandreou acknowledged the risk of tremendous job losses among drivers. Examining these possible job losses entails the identification of alternatives in the short- to medium-term along the supply chains, the characterization of the new jobs required for a fully automated freight system, and the identification of the corresponding education and training needs. They remarked that uncertainties also affect other jobs directly or indirectly related to freight operation, notably, in professions such as planning, traffic management, and parking. In addition, the massive adoption of artificial intelligence and machine learning is likely to further affect jobs currently held by humans. Lenz and Papandreou observed that the expected decrease in transportation costs may cause manufacturing industry to move further away from populated areas.

In discussing the impacts of Scenario 1 on equity, Lenz and Papandreou noted that more on-road shipments are likely to result in increasing levels of noise and air pollution, while the quality of life in urban areas is likely to be negatively affected by the diffusion of off-peak deliveries, thus calling for new options to relieve those living close to road infrastructures or in areas of frequent deliveries. However, they cautioned that residential areas underequipped for automated delivery may become delivery deserts, adding to the already existing retail and food deserts.

On data access and privacy, Lenz and Papandreou noted that Scenario 1 implies a loss of access to supply chain data by smaller firms, seriously hampering their capability to collaborate with other companies in the chain. They remarked that as access to data becomes a core asset for the freight business, the value of digital information must be carefully weighed against implementation costs. Issues raised therefore focus on the shifting role of the main actors. In such a shift, large e-commerce platforms could potentially acquire a dominant position across production, sales, and consumption, while wholesalers, small producers, dealers, and logistic operators could disappear.

The coauthors also commented on the potential role of Blockchain[3] technology in increasing security and trust, thus contributing to supply chain consolidation. At the same time, freight transport costs could also be driven up as a consequence of the reduced number of available options.

In addressing the fourth cross-cutting impact area of Scenario 1, safety and security, Lenz and Papandreou remarked that the early implementation of automation may raise safety issues and therefore lead to resistance against freight automation. Questions arise concerning the reliability of automation software in providing safer operations for both the driving and the loading/unloading of goods. In addition, these concerns generally related more to whether automation would limit the control capabilities of authorities and police on the nature of transported loads, their legitimacy, and the security of the goods.

Lenz and Papandreou introduced Scenario 2: Automated Road Freight Restrained by Policy. In this scenario, road automation is severely regulated, notably through

[3] Blockchain is a digital ledger in which transactions are recorded chronologically and publicly.

an obligation for low-emissions powertrains, while automation of rail and waterways is reinforced. New business models for dual use (freight/passenger) emerge, and the overall positive effects on safety and environment contribute to generate high public acceptance.

The coauthors discussed the implications of Scenario 2 on economics and the workforce. They observed that the effects of automation on regional economies are largely uncertain for both the deployment of the circular economy and also the pressure that automation may exert in restraining trade and forcing the preference of urban areas for locally made, grown, or developed products and delivery systems. In this scenario, regulation is in place to facilitate the labor transition, allowing it enough time. This regulation may, however, meet resistance from firms, states, cities, and citizens in accepting a slow pace that hinders the deployment of new businesses and transport systems. As in Scenario 1, appropriate education and (re)training needs must be swiftly appraised and short- to medium-term alternatives to immediate job losses identified.

In addressing the equity impacts of Scenario 2, Lenz and Papandreou noted that reduced transport costs would likely lead to an increase in purchasing power across income ranges, therefore including lower and middle classes, with unknown effects on household consumption and, subsequently, on production and trade of consumer goods. They argued that a reorganization of supply chain logistics may yield beneficial effects in residential areas, for instance, by promoting smaller and more locally focused distribution that helps eliminate food and retail deserts. In parallel, such reorganization may also free up land in urban areas that then can be used for equitable housing, healthcare, and education. The coauthors remarked that in this scenario, regulation might be required to ensure not only that the interests of businesses are not unduly prioritized against those of citizens, but also to ensure equitable curb access for freight delivery and other shared mobility services.

Concerning data access and privacy impacts, Lenz and Papandreou observed that much of the private sector data concern product mix, shipping times, end-consumers' behavior, and financial information. While their commercial value is in principle known to businesses, the value of public data, alone or in combination with private data, is uncertain. Ensuring data access for efficient operations while safeguarding the users' privacy raises several issues concerning the nature of data used or exchanged, the allocation of responsibilities in data management, and the optimal mix of public and private data such that the private sector is encouraged to collaborate. The coauthors remarked that such data systems may provide a throughput competitive advantage to regional and urban governments in promoting their ports, railways, and trucking systems for retail or end-consumer deliveries.

Lenz and Papandreou discussed safety and security impacts in Scenario 2. In this regulation-driven scenario, specific laws may be required to allow for digital inspections of automated freight and delivery vehicles and of freight transported along an automated supply chain. At the outset, it may be necessary to identify which inspections will still be needed with full digitization and increased traceability along the supply chain and to understand the resulting public trust in the automated system. The coauthors observed that automated delivery systems may contribute to establishing a safer urban environment and to reducing congestion and fatalities on major intercity relations such as through platooning. At the same time, the coauthors suggested that delivery vehicles would need to be designed so that pedestrians, persons with disabilities, and other vulnerable users would be duly accounted for.

Problem Statements and Suggested Future Research

The participants in the breakout groups identified problem statements and knowledge gaps and discussed how these could translate in future joint EU-U.S. research on the socioeconomic impacts of CAVs in the freight sector and for the people involved therein. Participants further discussed the extent to which digitization of freight operations may entail radical changes in overall travel patterns and in the organization of logistics. A number of participants acknowledged the limited public funding of research addressing the deployment of CAV-based freight transport systems, although the freight sector is likely to pioneer the transition to CAV. A selection of research ideas was presented in the closing session by the planning committee members responsible for this first exploratory topic. In addition, the rapporteur reviewed various sets of notes from the breakout groups. The result is as follows:

- Investigate the future/changing roles and responsibilities of drivers, which new or alternative tasks they could be assigned (e.g., at collection points for the last mile), and which other job opportunities exist at locations.
- Identify the education and (re)training requirements for workers with jobs at risk and the relevance of demographic variables (age groups).
- Explore new opportunities for collaboration between government, industry, and civil society, how their respective roles will change and which new governance frameworks are required to fully harness the CAV potential in the freight sector.
- Research the effects of freight automation on equity gaps and whether and to what extent a CAV-operated

freight transport system will have an impact on the capability of people to satisfy their basic needs and freedoms and whether an increasing digital divide may prevent access to automated freight services for specific socioeconomic groups.

- Examine requirements and opportunities for subsidizing automated freight infrastructure and its maintenance and investigate the societal acceptability of large public investments that will only (appear to) benefit a limited set of companies and communities.
- Assess the environmental impacts of automated freight and automated deliveries and their spatial and demographic distribution.
- Identify the intersection of data access and privacy with freight automation and investigate its socioeconomic effects.
- Examine whether and to what extent data exchange associated with freight automation can provide opportunities for developing novel multimodal solutions that are environmentally friendly and spatially efficient.
- Identify and establish safety standards, protocols, and indicators that a CAV-operated freight system is required to meet before it is fully deployed and scaled.
- Develop appropriate audiovisual communication cue protocols that maximize the security of loading/unloading automated freight vehicles.
- Devise and establish a research framework on the cybersecurity of automated freight and deliveries that overcomes shortcomings from the classified nature of most cybersecurity research.

The discussion in the breakout groups developed beyond the above list and raised a variety of supplementary issues that may enrich the design of future research programs. A short additional selection of possible research topics is provided below.

- Impacts of the new organization of work on the mental workload of personnel;
- Job losses outside the freight transport sector (e.g., rest areas);
- Changes in consumers' behavior as a result of urban delivery automation;
- Different day/night urban patterns and city livability;
- Impacts of built-in biases of algorithmic automation on the movement of goods;
- Opportunities from freight automation to redefine the social contract, that is, the respective rights and obligations of governments and citizens;
- Freight automation and location-based discrimination;
- Human-centric design of freight automation systems;
- Public incentives to foster data sharing;
- Automated urban deliveries and their impact on the current proliferation of gig jobs;[4] and
- New insurance models and liability frameworks reflecting the changes in roles and responsibilities.

Exploratory Topic 2
Places Where People Live, Work, and Play
Alex Karner and Marcin Stepniak

This exploratory topic addressed potential land use changes (e.g., residential density, employment density, square feet of retail space) that are likely to arise under two very different transportation automation futures.

Karner and Stepniak introduced Scenario 1: CAVs on the Rise, which assumes that the development of CAVs is driven purely by market forces. In this scenario, CAVs completely replace traditional vehicles, with a subsequent decrease in the attractiveness of nonmotorized modes. The cost of travel time tends toward zero, leading to an increase in trip lengths and in the intensification of development pressures to respond to the ensuing relocation trend. Demand for parking is reduced and concentrates in city centers, while the accelerated adoption of charging zones drives a growing need for drop-in/drop-out areas. The critical issue in Scenario 1 is accessibility to CAVs.

Karner and Stepniak discussed the impacts of Scenario 1 on economics and the workforce. They argued that the reduction in space allocated to parking may lead to an increased concentration of economic activity. The impact on firms' location choice will then depend on the extent to which development is transit-oriented. This scenario features an increased concentration of retail and services, which is likely to prompt the emergence and the prevalence of service hubs and the disappearance of smaller service locations. The coauthors noted that the impact on urban form is uncertain, as this scenario could result in the development of a polycentric city model but could also lead to bolstering monocentric urban structures.

In addressing equity issues raised by CAVs in this scenario, Karner and Stepniak observed that the main challenge is to ensure equitable access to CAVs. The primary concern is therefore to provide increased access for transport to disadvantaged populations, which notably

[4] Gig jobs are temporary, flexible jobs typically held by independent contractors and freelancers instead of full-time employees.

calls for policies and measures that offset the negative effects of the digital divide induced by the pervasive diffusion of mobile and banking technology. An additional hurdle toward serving disadvantaged populations is the reduction in public transit services that can be expected from the full reliance on CAVs. Concerning the impacts on land use, Karner and Stepniak cautioned against the risks of increasing segregation and place-based discrimination that could result from the massive adoption of CAV-based transport systems.

The coauthors examined the safety and security impacts in this scenario. They noted that CAVs promise to guarantee full protection against accidents resulting from human error. However, considering the inevitable spatial disparities in access to CAVs, they concluded that the spatial distribution of accident risk is subject to great uncertainty. Concerning security impacts, they remarked that a major distinction should be made between the security levels of shared and private CAVs. However, it is likely that mode choice (shared versus privately owned) will become dependent on place and time, altogether stressing the need to consider travel security as a driving factor.

Concluding the presentation of the first scenario, Karner and Stepniak discussed the arising data access and privacy issues. They observed that handling personally identifiable information on location choices is particularly critical and cautioned against the subsequent potential risks of both state and private discrimination. They also noted that access to information is bound to reflect on land value, with impacts on land management and on land speculation pressures.

Karner and Stepniak introduced Scenario 2: CAVs Tamed by Policy and People, which assumes that the development of CAVs is dramatically limited and highly regulated. In this scenario, the overall traffic volumes are reduced and nonmotorized modes become more attractive. Telework dominates, with smaller and shared AVs prevailing in the passenger sector while CAVs are used largely for the movement of goods. Changes in land use policy and practice induce a decline of local control while transport-oriented development is on the rise. The critical issue in this scenario is accessibility to places.

Karner and Stepniak discussed the impacts of Scenario 2 on economics and the workforce. The reduction in commute distances and times is expected to generate an overall increase in population health. Additional economic and workforce impacts will most likely stem from the diffusion of telework, which the coauthors observed may not follow a homogeneous pattern. Telework exhibits different degrees of adoption across sectors, while low-wage labor in all sectors is likely to remain largely place based. Altogether, telework patterns will probably result in differentiated impacts between economic sectors.

In addressing equity implications, Karner and Stepniak argued that Scenario 2 also features a significant potential for continued segregation, where prosperous areas with high shares of telecommuters retain an advantage over more deprived areas populated by commuters with restricted transport options. To mitigate such inequalities, non-CAV policies, such as the development of affordable housing, are required.

The coauthors commented on the safety and security impacts of Scenario 2. They noted that neighborhood effects may generate additional inequalities. Prosperous areas where commuting is reduced and CAVs operate more safely will probably enjoy a declining injury risk, whereas disadvantaged areas may suffer from an increasing risk. Karner and Stepniak raised the concern that in relation to disaster preparedness, the adoption of CAVs is likely to make large-scale evacuations difficult.

To conclude the presentation of Scenario 2, the coauthors discussed data access and privacy implications. They remarked that in this scenario, the limited uptake of CAVs inherently implies a reduced need for data collection. Data that would be collected are primarily associated with medium and long-range trips, making it possible to envisage a data collection system that would be operated and controlled at the local/decentralized levels (places) as opposed to a centralized manner (e.g., at the hands of a global company/agency), thus containing the risks of undue circulation and misuse. On the other hand, the previously advocated government intervention in the private housing market entails the collection of additional data.

Problem Statements and Suggested Future Research

Individual participants in the breakout groups identified problem statements and knowledge gaps, and discussed how these could translate in future joint EU-U.S. research on the socioeconomic impacts of CAV on the places where people live, work, and play. It was noted that any research related to AV implementation must consider different spatial contexts, notably the micro scale (streets), the mesoscale (urban/suburban/rural differentiation), and the macroscale (diversity across countries and world regions such as Europe, the United States, and the global south), with spatial impacts systematically analyzed through the prism of multimodality and interconnectivity between modes. The planning committee members presented a selection of research ideas in each exploratory topic during the closing session. In addition, the rapporteur reviewed notes from the breakout groups. The result is summarized in the following list.

- Examine how the advent of CAVs can help cities integrate shared mobility in their public transport strategy.

- Investigate public acceptance of long commuting trips and whether and how this is likely to change with the introduction of AVs.
- Estimate the extent to which a CAV-based transport system will influence travel time budgets and the subsequent direct impacts on land use patterns, urban forms (e.g., mono- versus polycentric), the distribution of residential areas, and the centralization of jobs.
- Research the potential contribution of CAVs to the mitigation of transport disadvantages, the effects of switching from fixed to variable costs, and the role of the public sector in subsidizing services in specific places.
- Identify and test new (including participatory) methods to assess equity impacts of transport policies and plans, as traditional workhorse tools like travel demand and land use models may prove unfit to gauge the equity performance of CAV-based transport systems.
- Develop pilot projects at different spatial scales (urban, suburban, rural), notably to link results of equity performance analysis to practice.
- Identify strategies and best practices for public–private data sharing and assess the extent to which such strategies are constrained by power wielded by local jurisdictions.
- Explore the potential for integration of data into a unified platform for transport system management covering many different modes and options and thus superseding the centrality of cars so far.
- Foster data integration and interoperability through the development of open data standards based on common use cases for cities and regions.
- Review and assess a range of options for leveraging and putting data to purpose, with particular emphasis on light detection and ranging (lidar) data.
- Develop an interdisciplinary approach to design infrastructure and public space in a CAV-dominated environment, including streets, parking areas, small traffic architecture (traffic signs, street lights), sharing spaces, and the associated users' prioritization.
- Research the impact of the dependency on AVs on failure/disaster management and devise protocols and procedures for evacuation in a CAV environment and for containing blackout implications, as CAVs rely heavily on the electricity supply.
- Review past and contemporary experiences to derive best practices in the transfer of lessons learned between different spatial and social contexts.

The discussion in the breakout groups developed a variety of supplementary issues that may enrich the design of future research programs. Additional possible research topics are as follows:

- Changes induced by CAVs on job location and how they differ across sectors;
- Shared mobility complementing or competing with public transport or both;
- Public acceptance of shift from fixed to flexible public transport schedules and routing;
- Distance-based pricing and the potential cost increase for the end user;
- Positive and negative effects of CAVSM on residential and employment segregation (friendly communities versus ghettos);
- Impacts of CAVs and increased accessibility on property values, gentrification, and displacement;
- CAV-driven risk of marginalization of pedestrians and cyclists;
- Risk of demographic discrimination, data requirements, and responsibilities;
- Sociotechnical enablers and barriers of CAV-based shared mobility;
- Rethinking public transit in low-density suburban areas;
- Policies and measures for intergenerational equity; and
- Urban resilience in the event of AV failure or insufficient availability.

Exploratory Topic 3
Impact of Automation on Travel Behavior

Alexandra Millonig and Susan Shaheen

This exploratory topic addressed the impacts on travel behavior of the automation of the transport of goods and people. Different CAV market penetration levels and policy contexts are likely to deeply affect public acceptance and mobility choices.

Millonig and Shaheen introduced Scenario 1: CAVs on the Rise and how it reflects on travel behavior. In this scenario, CAV services cater to a wide assortment of mobility needs, with different vehicle sizes and models. The ease of use and limited cost of CAV services makes them very popular, and demand for traditional transport modes has been dramatically decreasing, prompting severe cuts in public transport and the reduced use of nonmotorized modes. Despite the resulting increase in congestion, just about everyone is using CAVs, even for short trips, while mobility outside the urban core is almost entirely serviced by CAVs. Some reserved areas for pedestrians and microvehicles have been established in many cities, although retail activities have shrunk dramatically as on-line shopping is the norm. Travel cost savings also drive an increase in the shared use of CAVs, despite some resistance arising from security concerns.

Millonig and Shaheen discussed the implications of Scenario 1 on economics and workforce. They noted that the massive and wide-ranging take-up of CAVs is likely to spur the development of a variety of new business models, mostly from the private sector, which may in turn affect many professions in the transport sector (e.g., maintenance, traffic management). They remarked that the diversification and flexibility of CAV services will lead to increased individualization and personalization, thus offering new opportunities for start-ups, although the market may ultimately be dominated by a limited number of global actors. The overall implications on the labor market are yet largely unexplored. The coauthors observed that the development of a highly competitive transport market based on the massive advent of CAV services may induce radical changes in the definition of work, the quality of working environments, and the work–life balance, possibly leading to growth in the number of precarious jobs.

In addressing the equity implications of Scenario 1, Millonig and Shaheen noted that a new, largely CAV-based transportation system may have a negative impact on socioeconomic disparities, as privileged social groups are likely to receive higher priority on their trips while others may have to accept longer commute distances and times. This scenario may also have repercussions on people's health and well-being, as physical exercise is reduced along with opportunities for social interaction. The coauthors remarked that while the CAV promise is to facilitate accessibility for all social groups, including nondrivers such as those who are elderly, children, and persons with disabilities, Scenario 1 could also have the opposite effect, in that profit-oriented private operators might discriminate between users according to their purchase power. Other road users may also be discriminated against. For instance, pedestrians and cyclists could be banned from specific zones, or their access to these zones restricted, in order to avoid hazardous interferences with CAV fleets.

On data access and privacy issues, Millonig and Shaheen cautioned against the risk that in Scenario 1, the less affluent may be induced to surrender their privacy as their personal data (e.g., itinerary and time of travel, accompanying persons) become a source of revenue if sold to commercial interests. A further risk arises from the potential emergence of discriminatory practices, as service providers may use personal data to ban specific groups or manipulate their behavior by imposing less-than-optimal routes. Overall, trust is a critical issue, and the coauthors noted that privacy-concerned citizens may find it challenging to protect their personal data and might subsequently reduce their travel altogether.

To conclude Scenario 1, Millonig and Shaheen discussed CAV implications on safety and security. They observed that ethical issues may arise under specific circumstances, when, for instance, CAVs are programmed to decide who must be sacrificed in an unavoidable accident and whether economic worth is the guiding criterion. The coauthors argued that the perception of safety and security is also bound to affect the behavior of specific groups, such as women avoiding nighttime shared rides or people reducing their active mobility because walking and cycling are perceived as less safe. They observed that failures or malfunctions of the CAV system as the result of a cybersecurity breech were likely to affect groups like commuters and emergency workers more seriously, as they are more reliant on transportation access.

Millonig and Shaheen then introduced Scenario 2: CAVs Tamed by Policy and People and outlined its implications on travel behavior. This scenario is primarily driven by the vigorous enactment of ambitious climate and environmental goals, which translates into a decrease in traffic volumes and the subsequent rise of telework. It further entails radical changes in the production sector, making the most of emerging, trip-saving technologies such as automation and 3-D printing. Smaller, highly connected communities proliferate, where people concentrate most of their activities by working in local teleworking spaces and covering the majority of distances by walking or using shared bikes and microvehicles. Smaller passenger CAVs are primarily reserved for targeted services such as transporting persons with disabilities or feeding into larger hubs for mass transportation. The movement of goods, on the other hand, relies heavily on CAVs, as home deliveries prevail over traditional shopping. CAV services are largely operated by the public sector, and privately owned CAVs are mainly a status symbol for a small elite.

Millonig and Shaheen discussed possible impacts of Scenario 2 on economics and the workforce. They remarked that professions in the transport sector are also likely to be deeply affected in this scenario, as the automotive industry shifts its focus from private transport to community vehicles for special services and to smaller vehicles for goods transport. In addition, the automotive industry reorganizes production on a regional basis. New infrastructure could be needed to stimulate active modes, along with innovative products and services—to provide, for example walking aids using small robots—which may foster new businesses requiring new skills. The coauthors argued that the focus on regional and local economies is expected to improve job accessibility for several social groups, whereas the inherently limited working opportunities available at the local level might force other groups to move to find suitable employment opportunities. They noted that the rise of telework is expected to bring social benefits as flexibility in working time increases, but that the risks of interference with one's private life may also be enhanced, thereby affecting work–life balance and, ultimately, productivity.

Commenting on the equity dimension of Scenario 2, Millonig and Shaheen noted that existing social disparities might not disappear in this scenario and might even be exacerbated unless targeted regulation is enacted. They cautioned against the risk that living in local communities might reduce opportunities for social interactions with people outside the community, a trend that can easily breed intolerance and social instability.

Millonig and Shaheen discussed data access and privacy issues arising from Scenario 2. As daily activities are concentrated within a small spatial range, the boundaries between different aspects of life (work, family, leisure, community) can easily become blurred, and the handling of sensitive personal or professional data may suffer from unwitting negligence, affecting people's privacy. The coauthors remarked that strong local communities, which can enhance the sense of security, can also breed a high level of social control and ultimately limit individual freedom if any movement of persons and goods could easily be learned by other community members, and this movement could be recorded. They noted that for efficiency reasons, regional/local companies may be encouraged to combine the production of goods and the delivery of services in the region, thus gaining access to rich and comprehensive datasets on their customers.

Addressing the fourth cross-cutting impact area of safety and security in Scenario 2, Millonig and Shaheen argued that the safety promise of CAVs can hardly be upheld in this scenario. CAVs have only achieved a limited market uptake, and local traffic is increasingly served by walking and cycling. Longer distances will most likely be much less traveled, and as a consequence, the availability of infrastructure and services to move large numbers of people and large amounts of goods may be significantly reduced, posing potentially serious problems if natural disasters or terrorist attacks require fast evacuations or the quick supply of goods.

Problem Statements and Suggested Future Research

The participants in the breakout groups identified problem statements and knowledge gaps and discussed how these could translate in future joint EU-U.S. research on the behavioral changes arising from CAVSM. Participants noted that behavioral issues must be addressed with both an individual and a collective perspective and that trust in CAVSM services along with community and equity effects are crucial transversal concerns. A selection of research ideas was presented in the closing session by the planning committee members responsible for the exploratory topics. In addition, the rapporteur reviewed notes from the breakout groups. The result is as follows:

- Assess productivity changes induced by CAVSM, investigate whether being able to work while traveling will benefit different groups equally (e.g., full-time versus gig economy workers), and whether productivity changes will affect their work–life balance.
- Explore how commuting travel behavior is affected by work/home location decisions that are in turn driven by the availability of CAVSM and identify possible incentives that employers could provide to influence positive social outcomes.
- Review professions that are directly or indirectly linked to transport, how they are likely to change or disappear with CAVSM, which new or revised jobs may emerge, and which education and (re)training programs and tools are required to facilitate the transition.
- Analyze the impact of CAVSM on the labor market as a whole and on macroeconomic performances, considering both direct impacts in the transport sector and indirect impacts in sectors, such as manufacturing, that are heavily affected by technologies that reduce travel demand effects, such as 3-D printing.
- Investigate how potential changes in travel behavior and travel time use might affect the nature and social role of communities and how undesired effects such as spatial mismatch or the virtualization of social interactions can be avoided through targeted policy measures that support community development.
- Identify public policies (and their spatial differentiation) that can help CAVSM in reducing inequalities for disadvantaged groups, avoid the creation of new ones, and guide the deployment of innovative transportation services that leave no one behind.
- Research the nature and extent of the impacts of CAVSM on social inclusion and well-being, including potential risks of social isolation (from, for example, longer commutes), and on the propensity of users to take advantage of the opportunities for social interaction offered by shared mobility and their overall response to the time and cost tradeoffs of traveling with others.

- Review and further develop data protection methods, tools, and guidance that can enable the public sector to identify data requirements for CAVSM-based transport operations, assess data quality and the ethics of third-party data collection and analysis, and identify data sets that must be kept under the public responsibility.
- Explore opportunities for devising regulation and market-based mechanisms to ensure that the private sector duly considers societal good while pursuing legitimate profits in operating CAVSM.
- Identify user requirements for personal data-handling practices that ensure transparency and enable users' control while fostering the public good by improving network conditions, identifying safety risks, and encouraging safe travel behavior.
- Assess risks arising from potential data breaches and cybersecurity attacks and identify strategies and measures to minimize negative impacts and increase transport system resilience.
- Investigate how safety and security risks are perceived across sociodemographic groups and how they influence travel behavior.

The discussion in the breakout groups raised a variety of supplementary issues that may enrich the design of future research programs. A short additional selection of possible research topics is as follows:

- Role of emerging businesses in a small community context;
- CAV transition speed in different scenarios, also considering mixed traffic (CAVs and non-CAVs, active modes);
- New skills and education to address maintenance tasks;
- Limitations or bans on CAVs and their impacts on modal choice;
- Cultural differences and how they influence the perception of CAVSM and its safety;
- Second-level impacts of CAVSM on health and gender equality;
- CAVSM's possible contribution to antidisplacement policies (e.g., to limit city gentrification);
- CAVSM's possible contribution to curbing global industrialization trends;
- CAV-induced increases in mobility for groups with low travel demand;
- Cost-effectiveness and cost–benefit assessment frameworks for CAVSM systems, including all dimensions (economics, equity, safety and security);
- Risks of behavior manipulation resulting from machine learning based on willingness to pay;
- Potential behavioral changes of specific demographic groups to avoid being tracked or profiled;
- Secure methods to anonymize data with public transparency; and
- The role of Blockchain technology in building trust in CAVSM and protecting traveler privacy.

Exploratory Topic 4
What do Stakeholders do?

Matthew W. Daus and Satu Innamaa

Daus and Innamaa introduced the fourth exploratory topic by remarking that the advent of CAVs is bound to influence a wide variety of stakeholders who are expected to react and contribute to molding policy and CAV frameworks. Stakeholders can be grouped in categories that include public and quasi-public entities, users and impacted nonusers, automakers, private mobility companies, and technology companies. Each category is likely to react according to its role and interests, with public authorities devising regulation and determining the extent to which the market develops freely or enjoys subsidization, mobility service providers adjusting their workforce to account for the decreased need for drivers and the increased need of service developers, and all businesses enacting changes in job descriptions for drivers.

Daus and Innamaa presented the main features of Scenario 1: CAVs on the Rise. In this scenario, regulators choose to offer minimal intervention for the provision of mobility services. While this approach may result in a wider array of innovative private services, there is a risk that such services do not meet the needs of all segments of society and possibly lead to an increase in safety hazards. The transport system in this scenario primarily relies on private competing mobility services operating with privately owned AVs. The offering of public transport services is reduced, while CAV systems feature a rich assortment of traveler services, including infotainment, in-car working facilities, and parking services for private AVs.

Discussing the economic and welfare issues arising from Scenario 1, Daus and Innamaa argued that the huge expected job losses among for-hire drivers and other mobility operators and the resulting increase in unemployment will most likely have negative repercussions on overall transport demand. They also noted that the massive advent of CAVs will lead to the emergence of new and innovative mobility services ecosystems, the main challenge being how to support innovations that create jobs that benefit from the diffusion of CAVs.

Addressing the equity dimension, Daus and Innamaa observed that the private mobility services that largely prevail in Scenario 1 may not be affordable or accessible for all. This may be conducive to the introduction of differentiated levels of service where better quality is priced higher or to more discriminatory practices based on the selection of customers, or both. In a largely unregulated environment, mobility for special groups, such as those who are elderly and persons with disabilities, might be at risk. Commercial practices that lead to inequity increases may also emerge at regional levels, as service providers may focus on areas where profits are higher. Routing policies adopted by service providers then become critical, as they may directly affect accessibility for specific groups (e.g., poor neighborhoods, persons with disabilities). The coauthors further noted that conflicts of interest may occur in the definition of an adequate balance of benefits between cities and the private sector.

Daus and Innamaa reviewed the data access and privacy implications of Scenario 1. Against the backdrop of a transport system that relies on the massive adoption of CAVs primarily operated by private companies, service providers will likely collect huge amounts of big data on the mobility of their customers, which could allow for systematic profiling practices. In this scenario, no anonymity or privacy guarantee will realistically be available to travelers, and no open data policy will likely be in place. On the other hand, service providers will be able to seize additional business opportunities by vending data or information elaborated therefrom. It can be expected that cybersecurity services will bloom in this scenario to help offset the privacy threats associated with a largely unregulated transport system.

To conclude the presentation of Scenario 1, Daus and Innamaa discussed its safety and security implications. They observed that in a typical situation of mixed traffic, CAV users will in principle be better protected than other road users. However, this scenario features an overall rise in traffic volumes and in mileage, which is likely to increase exposure to crashes and, at the same time, decrease the safety of vulnerable users. The coauthors also noted that driverless ridesourcing may compromise security, or at least its perception.

Scenario 2: CAVs Tamed by Policy was introduced. In this scenario, regulation is prescriptive over the introduction of CAV-based mobility services. Daus and Innamaa argued that while stringent regulation is bound to impose constraints on innovation and therefore hinder or slow down the development of innovative transport services, such regulation is conducive to a more-defined vision of how these innovative services could achieve the ultimate goals of increasing safety and improving mobility for all. In Scenario 2 the transport system primarily relies on public transport, which includes demand-responsive and CAV-based mass transit services. The transportation system features well-functioning, possibly intermodal transport chains and benefits from public–private collaboration with targeted subsidies ensuring a minimum level of mobility services for all. Private CAVs are part of the system, but are expensive and heavily taxed. Services available to CAV travelers include multimodal mobility, first mile–last mile, intelligent journey planners, and infotainment.

Daus and Innamaa discussed the implications of Scenario 2 on economics and welfare. Although at a slower and more deliberate pace than in Scenario 1, significant changes in the workforce will most likely take place, with a decrease in for-hire drivers, and an increase in the personnel needed to develop and operate CAV-based public transport services and the associated information resources. Public/private collaboration could ease the financial and welfare burden arising from job losses and help to better identify and enact education and training programs that meet the new skills requirements. Public transport operators will need to adequately prepare for significant changes in their cost structure.

Addressing social equity issues arising from Scenario 2, Daus and Innamaa argued that it might be easier to guarantee basic transport services to all people in all regions, while additional services will be offered at a price. This notwithstanding, the difference in mobility between the affluent and the rest of society is likely to remain significant. Public subsidies, which play an important role in this scenario, will need to be carefully assessed against their potential impacts in the short and long term.

The coauthors then reviewed the data access and privacy dimension. They noted that in this scenario, where public CAVs prevail, mobility data are owned by public authorities, which makes it possible to ensure the anonymity and privacy of travelers for at least some public services, while user identification might be inevitable for others. All in all, this scenario offers a much greater potential for open data.

Daus and Innamaa finally commented on the safety and security implications of Scenario 2. They argued that smaller traffic volumes, at least in terms of the number of vehicles, are likely to reduce exposure to crashes and, therefore, the associated crash risk for all users, including the most vulnerable. On the other hand, driverless public transport rides may be perceived as less safe by many travelers.

Problem Statements and Suggested Future Research

The participants in the breakout groups identified problem statements and knowledge gaps and discussed how these could translate in future joint EU-U.S. research on the role and attitude of stakeholders engaged in the CAVSM transition. Participants remarked that the transportation ecosystem is expanding with CAVs, and the number of stakeholders involved is thus proliferating. Not surprisingly, many emerging research priorities involve shifting concepts of ownership, control, and responsibility. In the perspective of EU-U.S. cooperation, the participants further noted that more commonalities exist on the cross-cutting issues of economics and welfare and of safety and security than on equity and data access and privacy. A selection of research ideas was presented in the closing session by the planning committee members responsible for the exploratory topics. In addition, the rapporteur reviewed notes from the breakout groups. The research ideas are summarized in the following list.

- Assess the extent of potential revenue losses and gains due to the advent of CAVs for government and other stakeholders alike, and investigate alternative revenue sources to compensate for government revenue losses.
- Identify intangible benefits arising from CAVSM, such as productivity increases and enhanced quality of travel, and devise methods to estimate/quantify them.
- Investigate the possible reactions of various stakeholders to job losses and reclassification, building on lessons learned from comparable automation-driven transitions.
- Devise models for partnership and collaboration—along with their performance measures—that can ensure a smooth transition from large-scale traditional public transit to an ecosystem of multiple smaller and largely private mobility operators.
- Establish best practices and new paradigms for long-term and short-term planning to support government agencies' planning capabilities, considering the uncertainty of CAV impacts for various stakeholders.
- Explore the scope and effectiveness of possible regulation and market-based mechanisms (e.g., subsidies) to provide minimum mobility services for all.
- Investigate the equity implications of CAVs for various stakeholders with equity concerns (e.g., age, ability, race/ethnicity, place, income) and identify the need for regulation, subsidies, and PPPs.
- Design and validate effective approaches and techniques to foster collaborative stakeholders' involvement in addressing the equity implications of CAVs.
- Define feasible business models, service concepts, and partnerships among various stakeholders to address barriers and opportunities in the provision of CAV mobility services for older adults.
- Identify inequities among mobility service stakeholders, whether in economics (e.g., subsidies) or regulation, in order to ensure a fair playing field among providers.
- Collect and organize high-quality systematic and consistent accident data covering large regions to support CAV-related research, development, and establishment of effective roadworthiness testing procedures.
- Investigate the relative value of CAV data to different stakeholders in relation to their use and assess consumer awareness of data value and public acceptance of their use.
- Appraise specific data requirements to support research on the socioeconomic impacts of CAVSM, possible data sources, and privacy issues.
- Review the existing process of driver training on safety issues (e.g., use of simulators, driving license, emergency procedures), and identify necessary changes to ensure safe CAV operation.
- Design and establish the safety assessment process for CAVs with the support of original equipment manufacturers, public safety validators, and insurance companies, including the identification of specific criteria and methods for assessing roadworthiness.
- Assess the cybersecurity risks and requirements of CAVs and develop best-practice solutions or a code of conduct assigning responsibilities among various stakeholders, or both.
- Investigate consumers' mental models on CAV technology, its performance, and use/misuse, to better understand the potential risk of misuse.
- Establish a body of regulation for unaccompanied minors in shared mobility CAVs.
- Investigate issues arising from the tele-operation of privately owned, fully automated CAVs to define responsibilities and establish the required protocol for tele-interventions.
- Explore the risks of driverless trucks for the security of goods on board and the means for different stakeholders to overcome the risks.

The discussion in the breakout groups developed a variety of supplementary issues that may enrich the design of future research programs. Additional possible research topics are as follows:

- Role of unions and union politics in CAV transition,
- Persistence of emotional attachment to owned cars as traditional cars are replaced by CAVs,
- Minimizing empty CAV rides,
- Redesign of traffic management for new CAV mobility services,
- Scalability and replicability of successful CAV services,
- Value creation of (combining) data and dependence on the extent to which data are or can be shared, and
- Trade-offs between safety and security.

Closing Session

Clara de la Torre, *Directorate-General for Research and Innovation, European Commission, Brussels, Belgium*
Robert Missen, *Directorate-General for Mobility and Transport, European Commission, Brussels, Belgium*
Neil J. Pedersen, *Transportation Research Board, Washington, D.C., USA*
Alasdair Cain, *U.S. Department of Transportation, Washington, D.C., USA*

Closing Debate: Last-Chance Assertions

Following the presentation of the breakout groups' results, the members of the planning committee moderated a short debate where participants shared their final comments and suggestions. The following list summarizes some important issues addressed.

- Public–private collaboration is a cross-cutting feature that could be included in the discussion of all themes and topics.
- Road pricing schemes for CAVs could be investigated.
- Additional focus is needed on the overall sustainability (economic, social, and environmental) of the transport system.
- More attention could be devoted to policy challenges in the real world.
- Further interaction and collaboration are required with public transport operators and local governments.
- Health impacts deserve more attention.
- The opportunity could be seized to explicitly include CAVSM in the EU Sustainable Urban Mobility Plans.

Closing Comments from the European Commission

Clara de la Torre and Robert Missen

Clara de la Torre congratulated the participants for the valuable inputs provided throughout the symposium, as the topic selected for the event is indeed a challenge for the research agendas of both the European Union and the United States.

She reiterated that one of the strengths of EU research and development framework programs is to be fully open to cooperation with partners beyond Europe. This is already true for Horizon 2020, and the Work-programme for the final years of Horizon 2020 offers short-term opportunities to collaborate on the symposium topic. In the longer term, Horizon Europe sets out to confirm and enhance EU openness to international research partnership, thus recognizing the added value that co-creation can generate in addressing challenges of common interest.

De la Torre announced the forthcoming 2nd European Conference on Connected and Automated Driving that the European Commission will hold in Brussels on April 2–3, 2019, and invited all participants to join and contribute with inputs and insights.

She concluded by reiterating her thanks to the cochairs, Barbara Lenz and Susan Shaheen; to the other members of the planning committee, Matthew W. Daus, Satu Innamaa, Alex Karner, Alexandra Millonig, Marcin Stepniak, Timothy Papandreou, and Barry Ensig; to the authors of the white paper, Johanna Zmud and Nick Reed; to the keynote speakers, Karel Martens and Michael Ableson; to the symposium rapporteur, Andrea Ricci; and to all participants for their contributions.

Robert Missen expressed his appreciation for the hard work done in preparing the symposium and, most importantly, for the quality of the input it generated, which will help to shape a successful advent of CAVSM and to mitigate its adverse socioeconomic impacts. The outcome of the symposium will undoubtedly prove very useful in the forthcoming discussions with EU member states and with U.S. agencies, and Missen encouraged all concerned to follow up on the conclusions of the symposium at the next TRB Annual Meeting in January 2019.

Closing Comments from the Transportation Research Board

Neil J. Pedersen

Neil Pedersen congratulated the participants for the concreteness of their contributions, noting that the discussions produced real problem statements and research ideas. He highlighted the importance of defining and agreeing upon an adequate terminology, which the symposium indeed contributed to, and expressed his appreciation for the emphasis placed on the acceptance concept and on the role of the public sector, as public awareness and education are crucial to ensure a successful transition.

Pedersen also stressed the importance of case studies to collect empirical evidence and remarked that defining research priorities is a first essential step, but research results must then be used. He called for a close collaboration with the implementing agencies and the design of cooperative research programs.

Pedersen concluded by confirming that a dedicated workshop on the symposium outcome will be organized at the 2019 TRB Annual Meeting, held January 13–17. This workshop will be an opportunity to sustain the trend that moves from the discussion on technologies to one that focuses on other aspects. TRB offers a huge outreach potential which can only be fully deployed if all parties contribute.

Closing Comments from the Department of Transportation

Alasdair Cain

Alasdair Cain expressed his appreciation for the choice of the topic of the symposium. He remarked that current research activities on CAVs focus primarily on the technological side, while there is an urgent need to address the "softer side" of automation. From the perspective of EU-U.S. cooperation, he stressed that the symposium outcome successfully paves the way toward the next cycle of twinning activities.

Potential Portfolio for EU-U.S. Research on Socioeconomic Impacts of CAVs

Andrea Ricci, *Institute of Studies for the Integration of Systems (ISINNOVA), Rapporteur*

Andrea Ricci served as the rapporteur of the symposium. He drafted summaries of the general sessions and of the breakout groups, including keynote speeches and the presentations of the white paper and of the exploratory topics. He also attended breakout group sessions to gain a better understanding of the challenges and of potential topics for future research discussed by the participants, and he collected and analyzed notes prepared by the moderators to gather additional insights on the topic-related debates and their outcomes.

The rapporteur developed a potential portfolio for EU-U.S. research on the socioeconomic impacts of CAVs. Notwithstanding some inevitable overlaps, the potential research topics can be grouped by the following subject areas: transport ecosystem, governance, and public policies; impact evaluation; regulation and standards; strategies, planning, and best practices; acceptability; and data, methods, and tools. These research topics may be considered by the European Commission, TRB, and other funding agencies and research program owners on both sides of the Atlantic when devising their future research agendas and prioritizing projects and twinning opportunities.

Transport Ecosystem, Governance, and Public Policies

The advent of CAVs and shared mobility will induce radical changes in the structure and functioning of the transport ecosystem, with a proliferation of the type and number of stakeholders and a redefinition of many roles and responsibilities. The smooth and successful deployment of a new CAVSM-based transport ecosystem requires new governance frameworks and public policies that anticipate and effectively address the full range of expected impacts. Research in the following areas would help to adequately inform this transition.

- Devise models for partnership and collaboration—along with their performance measures—that can ensure a smooth transition of public mass transit toward a new, CAV-based ecosystem.
- Review all professions that are directly or indirectly linked to transport, the relevance of demographic variables, how these professions are likely to change or disappear with CAVSM, which new or revised jobs will emerge, and which education and (re)training programs and tools are required to facilitate the transition.
- Investigate the future and changing roles and responsibilities of drivers, the new or alternative tasks to which they could be assigned (e.g., at the collection points for the last mile), and which other job opportunities exist at locations.
- Investigate how potential changes in travel behavior and travel time use might affect the nature and social role of communities in a CAVSM-dominated landscape and how undesired effects such as spatial mismatch or the extreme virtualization of social interactions can be avoided through targeted policy measures that support community development.
- Explore new opportunities for collaboration between government, industry, and civil society; how their

respective roles will change, and which new governance frameworks are required to fully harness the CAV potential.

- Identify public policies and their spatial differentiation that can help mitigate the potential negative effects of CAVSM on disadvantaged groups and guide the deployment of innovative transportation services that leave no one behind.
- Design and validate effective approaches to foster stakeholders' involvement in addressing the equity implications of CAVs.
- Identify and address inequities among mobility service stakeholders, whether through economics (e.g., subsidies) or regulation to ensure a fair playing field among providers.
- Devise and establish a research framework on the cybersecurity of automated freight and deliveries that overcomes the shortcomings arising from the classified nature of most cybersecurity research.

Impact Evaluation

CAVSM will generate a wide variety of impacts, well beyond those affecting the performance of the transport system. Their identification and their quantitative estimation call for novel, multidisciplinary research efforts as highlighted below.

- Analyze the impact of CAVSM on the labor market as a whole and on macroeconomic performances, considering both direct impacts in the transport sector and indirect impacts in sectors such as manufacturing that are heavily affected by technologies such as 3-D printing that reduce travel demand effects.
- Assess productivity changes induced by CAVSM, investigate whether being able to work while traveling will equally benefit different groups (e.g., full time versus gig economy workers), and whether productivity changes will affect the groups' work–life balance.
- Research the effects of freight automation on equity gaps and the extent to which a CAV-operated freight transport system will affect the capability of people to satisfy their basic needs and freedoms. Explore whether an increasing digital divide may prevent access to automated freight services for specific socioeconomic groups.
- Assess the extent of potential revenue losses and gains arising from the advent of CAVs for government and other stakeholders, and investigate alternative revenue sources to compensate for any government revenue losses.
- Assess the environmental impacts of automated freight and automated deliveries and their spatial and demographic distribution.
- Estimate the extent to which a CAV-based transport system will influence travel time budgets and the subsequent direct impacts on land use patterns, urban forms (e.g., mono versus polycentric), the distribution of residential areas, and the centralization of jobs.
- Explore how commuting travel behavior is impacted by work and home location decisions that are in turn driven by the availability of CAVSM and identify possible incentives that employers could provide to influence positive social outcomes.

Regulation and Standards

The rapid diffusion of CAVSM technologies, solutions, and practices may lead to market failures along with other unintended consequences arising from the inappropriate use of technology or from unresolved conflicts of interest. Research could identify regulatory measures and inform the establishment of standards in critical areas such as the following:

- Investigate possible regulation and market-based mechanisms (e.g., subsidies) to provide minimum mobility services for all.
- Investigate the equity implications of CAVs for various stakeholders with equity concerns (e.g., age, ability, race/ethnicity, place, income) and identify the need for regulation, subsidies, and PPPs.
- Explore opportunities for devising regulation and market-based mechanisms to ensure that the private sector duly considers societal good while pursuing legitimate profits in operating CAVSM.
- Identify and establish safety standards, protocols, and indicators that a CAV-operated freight system is required to meet before it is fully deployed and scaled.
- Foster data integration and interoperability through the development of open data standards on the basis of common use cases for cities and regions.
- Design and establish the safety assessment process for CAVs with the support of original equipment manufacturers, public safety validators, and insurance companies, including the identification of specific criteria and methods to assess roadworthiness.
- Research the impact of dependency on AVs with regard to failure and disaster management and devise protocols and procedures for evacuations in a CAV environment and for containment of blackout implications, as CAVs rely heavily on the electricity supply.

- Establish a body of regulation for unaccompanied minors in shared mobility CAVs.
- Investigate issues arising from the tele-operation of privately owned, fully automated CAVs in order to define responsibilities and establish the required protocols for tele-intervention as the need arises.

Strategies, Planning, and Best Practices

Research is also needed to inform new strategies and planning approaches that anticipate and adequately address a wide range of critical changes in the transport ecosystem arising from the advent of CAVSM. Pilot projects and the identification of best practices can play a major role. The following research topics are suggested:

- Establish best practices and new paradigms for long-term and short-term planning, including through an extension of the scope and mandate of the Sustainable Urban Mobility Plans, to support government agencies' planning capabilities considering the uncertainty of CAV impacts for various stakeholders.
- Examine how the advent of CAVs can help cities integrate shared mobility in their public transport strategy.
- Develop an interdisciplinary approach to designing infrastructure and public space in a CAV-dominated environment, including streets, parking areas, small traffic architecture (traffic signs, street lights), sharing spaces, and the associated users' prioritization.
- Examine whether and to what extent data exchange associated with freight automation can provide opportunities for developing novel multimodal strategies and solutions that are environmentally friendly and spatially efficient.
- Develop pilot projects at different spatial scales (urban, suburban, rural), notably to link results of equity performance analysis to practice.
- Identify strategies and best practices for public–private data sharing and assess the extent to which such strategies are constrained by power wielded by local jurisdictions.
- Assess risks arising from potential data breaches and cybersecurity attacks, identify strategies and measures to minimize negative impacts and increase the resilience of the transport system, and develop best-practice solutions or a code of conduct assigning responsibilities among various stakeholders, or both.
- Define feasible business models, service concepts, and partnerships among various stakeholders to address barriers and opportunities in the provision of CAV mobility services for older adults.
- Explore the risks of driverless trucks for the security of goods on board and the means for different stakeholders to overcome the risks.
- Review the existing process of drivers' training on safety issues (e.g., use of simulators, driving license, emergency procedures) and identify necessary changes to ensure safe CAV operation.
- Review past/contemporary experiences from other automation-driven transitions to derive best practices in the transfer of lessons learned between different spatial and social contexts.

Acceptability

It is now widely established that new technologies can only be successfully deployed if their worth is fully recognized by all stakeholders involved and, most importantly, if they are well accepted by the community of users. Accordingly, policies and strategies are increasingly shifting their focus from the maximization of technology diffusion to the satisfaction of people's needs and aspirations. Acceptability of CAVSM and of its perceived impacts on society is yet largely understudied and calls for targeted research efforts as suggested in the following list.

- Investigate how safety and security risks are perceived across sociodemographic groups and how they influence travel behavior.
- Investigate consumers' mental models of CAV technology and its performance and use this information to understand the potential risk of misuse.
- Investigate public acceptance of long commuting trips and whether and how these trips are likely to change with the introduction of AVs.
- Research the nature and extent of impacts of CAVSM on social inclusion and well-being, the propensity of users to take advantage of the social interaction opportunities offered by shared mobility, and their overall response to the time and cost tradeoffs of traveling with others.
- Identify user requirements for personal data-handling practices that ensure transparency and enable users' control while fostering the public good by, for example, improving network conditions, identifying safety risks, and encouraging safe travel behavior.
- Investigate the relative value of CAV data to different stakeholders in relation to their use, and assess consumer awareness of data value along with the public acceptance of their use.
- Examine requirements and opportunities for subsidizing automated freight infrastructure and its

maintenance and investigate the societal acceptability of large public investments that will only (appear to) benefit a limited set of companies and communities.

Data, Methods, and Tools

CAVSM introduces radical changes in the transport ecosystem, with new stakeholders appearing along with new services, new risks, and a wide array of largely unexplored impacts that affect the entire economy. Accordingly, many of the knowledge gaps to be faced require additional data and new data collection and management approaches as well as new methods and tools to exploit them. Research could address the following challenges:

- Appraise specific data needs to support research on the socioeconomic impacts of CAVSM, the possible data sources, and privacy issues.
- Collect and organize high-quality homogenous accident data covering large regions, to support CAV-related research, development, and establishment of effective roadworthiness testing procedures.
- Explore the potential for integration of data into a unified platform for transport system management that covers many different modes and options and thus supersedes the centrality of cars so far.
- Review and assess a range of options for leveraging and putting data to purpose, with particular emphasis on lidar data.
- Identify and test new (including participatory) methods for assessing equity impacts of transport policies and plans, as traditional, workhorse tools such as travel demand and land use models may prove unfit to gauge the equity performance of CAV-based transport systems.
- Review and further develop data protection methods, tools, and guidance that can enable the public sector to identify data requirements for CAVSM-based transport operations, assess data quality and the ethics of third-party data collection and analysis, and identify data sets that must be kept under the public responsibility.
- Identify intangible benefits arising from CAVSM such as increased productivity and enhanced quality of travel and devise methods to estimate and quantify them.
- Develop appropriate audiovisual communication cue protocols that maximize the security of loading and unloading automated freight vehicles.

APPENDIX A: WHITE PAPER

Synthesis of the Socioeconomic Impacts of Connected and Automated Vehicles and Shared Mobility

Johanna P. Zmud, *Texas A&M Transportation Institute, USA*
Nick Reed, *Bosch, United Kingdom*

Summary

Vehicles that are increasingly connected, automated, and shared have the potential to change personal, freight, and public transportation profoundly. While the transition to widespread adoption of connected and automated vehicles and shared mobility (CAVSM) is underway in the United States (U.S.) and in the European Union (EU) Member States, uncertainty exists around the pace, scope, and impacts of the potential end states of the transition. The potential benefits to society are immense. On the other hand, the technologies will solve some problems but could also create new ones. This paper discusses the high level implications of CAVSM on four important socioeconomic issues: data privacy and access, safety and security, economics and workforce, and equity. Key points related to these four topics are presented below.

Data Privacy and Access

CAVSM is characterized by unprecedented volumes and new types of data. These data are used to improve traffic and vehicle safety, environmental outcomes, and accessibility; streamline the movement of people and goods; and bring direct commercial benefit through provision of innovative customized mobility services. Positive socioeconomic outcomes are contingent on adherence to voluntary or regulatory guidelines for data privacy protection and to established protocols for data access and use. CAVSM has the potential to weaken traditional means of protecting individuals' privacy through its broad reliance on various mobile, sensor, global positioning, computing, or other digital technologies, leading to increased privacy risk. Some examples of CAVSM information that could identify an individual include credit card transactions, biometric data as well as video data or GPS tracks. A single piece of data can be personally identifiable information (PII), such as an address. Likewise, multiple pieces of data when merged can be PII, even when the individual pieces would not be. Treatment of PII is distinct from other types of data because it needs to be not only protected but also collected, maintained, and disseminated in accordance with the fair information practices (in the United States) or according to regulation (in the European Union). While the United States and the European Union have privacy frameworks in place, there is no specific legislation or regulations that speak to the ownership and security of personal information generated or transferred by CAVSM.

Safety and Security

Traffic safety benefits are a fundamental motivator for connected and automated vehicle (CAV) development and deployment. More than 90% of traffic crashes are estimated to be caused by human error. CAV is expected to mitigate crash risk stemming from human error with the potential for significant societal benefits. However, evidence of the safety benefits are still being gathered, primarily through public road testing of the vehicles taking place both in the United States and in EU Member States. Not only may CAVs mitigate some errors, but also they may introduce new types of driving and vehicle operation errors. As with CAVs, shared mobility operations have the potential to both mitigate and exacerbate human-error caused traffic crashes. In terms of the former, shared mobility operations could provide alternatives to driving for some at-risk drivers; in terms of the latter, increased congestion at the curbside due to proliferating pick-ups and deliveries increases potential for crashes among vehicles as well as other road users. In addition, as software and connectivity play a much bigger and more critical role for the safe operation of CAVs, these vehicles may be at greater risk for cyber-attacks. Security by design is an approach followed to mitigate cyber risk in both the United States and in the European Union.

Economic and Workforce Issues

Mobility is directly associated with economic prosperity. Thus, the introduction of CAVSM services could influence the availability, cost, and efficiency of freight and passenger transport services. The movement of goods is often cited as a low-margin activity, and so improvements in efficiency through CAV is being aggressively pursued in the freight sector. Automation of the long-haul truck driving task has been estimated to reduce total transportation costs by about a third through 2040. Real-world trials of truck platooning have shown specific improvements in fuel efficiency. CAVSM also is expected to improve passenger transportation opportunities for many segments of society. Connectivity and shared transportation can be used to enable greater demand responsiveness, while automation may be able to reduce operating costs. However, these outcomes may lead to induced demand and increases in vehicle travel and emissions if demand is not responsibly managed. CAVSM operations also reflect the emergence of the so-called 'platform' or 'gig' economy, which offers flexibility for workers but may lack social protections. However, it is the potential for automated vehicles (AVs) to reduce employment that is perceived as a key concern. The International Transport Forum has predicted that up to 4.4 million trucking jobs could be eliminated in the United States and Europe; similarly a U.S. study suggests that automation is likely to have significant negative impact on truck drivers, bus drivers, and taxi drivers. It should be noted that automation may also create new employment opportunities.

Equity

Social equity relates to the fair distribution of services across potential recipients. For CAVSM, the vehicle designs and technologies used, the market segments addressed, and the regulations imposed upon such services are all factors that influence how mobility benefits will be distributed. For example, the best safety systems are currently being fitted primarily on new luxury vehicles. It will take the cascading of such safety systems from luxury to mass-market vehicles for the equitable distribution of safety benefits. Four significant areas where CAVSM might have positive equity impacts—access to employment, access to education, access to health services, and access to discretionary travel for social purposes—support greater societal well-being. An important issue of equity is the extent to which transport services enable those with additional travel needs, such as the disabled and/or elderly to satisfy their mobility requirements. Questions of who gets served and at what cost are significant policy issues to guide the proliferation of CAVSM.

Introduction

Key Takeaways

- In the United States, automated vehicle (AV) and connected vehicle (CV) systems are viewed as independent technologies, whereas in Europe they are seen as complementary.
- Connectivity is seen to be a major enabler for driverless vehicles in the medium term.
- AVs can be connected, whereas CVs will not necessarily be automated.
- Connected and automated driving facilitates the conditions for shared mobility services, which refers to a business model in which physical assets are accessed sequentially or concurrently by multiple users on a pay-per-use basis.
- Coupling the development of new CAVSM to emerging communication standards may delay exploitation of the benefits that CAVSM may offer.

The purpose of this paper is to provide foundational information on the socioeconomic impacts of AVs, connected vehicles (CVs), and shared mobility, covering the transport of people and goods. When referencing all three of these mobility technologies, the acronym CAVSM is used in this paper. Because CAVSM mobility innovations are developing and proliferating at a rapid pace, there is a need for informed, proactive, and consistent evaluation in the planning, deployment, and assessment of them and their potential socioeconomic impacts. This is important not only now as they operate as independent mobility services, but also in the future as the three technologies integrate in emerging applications, such as CAVs and shared automated vehicles (SAVs). This paper assumes that AVs can be connected, whereas CVs will not necessarily be automated.

Descriptions of CAVSM

AV technologies represent a switch in responsibility for the driving task from human to machine. They encompass a diverse range of automated technologies, ranging from relatively simple driver assistance systems to fully automated (or autonomous) vehicles. The Society of Automotive Engineers (SAE) International has categorized the levels of automation into six levels (see sidebar). A highly automated vehicle (Levels 4 and 5) does not require a steering wheel, accelerator or brake pedal. AV driving functionality is handled through onboard computers, software, maps, and radar and lidar sensors. Highly automated vehicles are not yet operating freely on public roads (other than as pilot programs). Currently, vehicles available to consumers are primarily Level 1 or 2 automation.

Since most passenger and commercial vehicle traffic accidents are caused by "human errors," the safety benefits AVs could provide are compelling–although incontrovertible empirical proof that AVs deliver safety benefits has yet to be produced. Other potential benefits relate to congestion mitigation, air pollution and greenhouse gas (GHG) reduction, and mobility enhancement for underserved populations, such as low-income people, older adults, the disabled, and rural residents. Supported by advancements in artificial intelligence (AI)–particularly in the areas of Big Data analytics, machine learning and knowledge management–rapid progress is being made in terms of AV development and deployment.

A CV has internal devices that enable it to communicate wirelessly with other vehicles, as in vehicle-to-vehicle (V2V) communication, or with an intelligent roadside unit, as in vehicle-to-infrastructure (V2I) communication. V2V applications enable crash prevention, and V2I applications enable telecommunication, safety, mobility, and environmental benefits. The acronym V2X is sometimes used to designate vehicle-to-everything (including pedestrian and bicyclist) communication. Data communications that enable real-time driver advisories and warnings of imminent threats and hazards on the roadway are the foundation of connected vehicles (Hong et al. 2014). At present, the V2I and V2V applications solely provide driver alerts; they do not control vehicle operations. Dedicated short-range communication (DSRC) and 4G-LTE are two widely used candidate schemes for CV applications, and 5G is on the horizon.

In Europe, the term "connected and automated driving" (C&AD, or CAD) refers to a set of systems using sensors, AI, and other technologies that enable vehicles to travel without direct human operation and to exchange information wirelessly with other vehicles, infrastructures and third-party service providers (European Commission 2017b). In the United States, AV and CV systems are often viewed as independent technologies, whereas in Europe they are seen as complementary. Connectivity is seen to be a major enabler for driverless vehicles in the medium term.

C&AD facilitates the conditions for shared mobility services. Unlike CV and AV that refer specifically to technology, shared mobility refers to a business model in which physical assets (e.g., bicycles, automobiles, delivery trucks, etc.) are accessed sequentially or concurrently (e.g., pooling) by multiple users on a pay-per-use basis. This model enables users to obtain short-term access to transportation services as needed and with seamless payment transactions mainly through mobile devices or online platforms (Shaheen et al. 2017a). Shared mobility is an alternative to ownership, or it may complement car ownership in households and conventional public transport. According to McKinsey & Company, Europe and the United States represent two of the three core regions comprising a shared mobility market of nearly $54 billion in 2016 (Grosse-Ophoff et al. 2017). The United States is one of the largest markets at $23 billion and is dominated by ridesourcing, while Europe is much smaller at just under $6 billion and leans more

Levels of Automation

Level 0: No automation.

Level 1: Human controls driving, but the automated systems can take over one major driving function, such as steering or speed.

Level 2: Human is responsible for safety-critical functions. Automated systems can execute both steering and acceleration/deceleration functions to assist driver. Most automakers are currently developing vehicles at this level.

Level 3: Vehicle can manage all safety-critical functions under certain conditions, but human is expected to take over driving tasks when alerted.

Level 4: Vehicle is self-driving in some conditions or situations but not all.

Level 5: The car can be completely self-driving in all situations. Requires absolutely no human participation in driving task.

toward carsharing. The convergence of C&AD and shared mobility is known as SAV, and there are various small-scale pilots in the United States and in EU Member States as discussed later in this paper. Many people believe that highly automated vehicles will first be available to consumers as SAVs (The Economist 2018). Cost is a main factor. Lidar sensors are still too expensive to be used in mass produced vehicles. The cost of this technology is considered less of a barrier for fleet vehicles because they will be generating revenue throughout the day to cover the expense, whereas the typical privately owned vehicle is used for a small fraction of a day.

The key enabler for CAVSM is communication of location and status data and an ability to analyze and interpret this data intelligently. While emerging forms of connectivity (e.g., DSRC; 5G mobile communications) offer promise for new communication services, many practical benefits of CAVSM can be achieved over existing mobile networks in the majority of the United States and EU Member States. Coupling the development of new CAVSM to the emergence of emerging communication standards may delay exploitation of the benefits that CAVSM may offer.

The next section provides a brief summary of the regulatory frameworks for CAVSM in the United States and in the European Union as a general context to inform the topical discussions that follow.

Regulatory Frameworks

United States

The U.S. Department of Transportation (U.S. DOT) published a federal automated vehicle policy via the National Highway Traffic Safety Administration (NHTSA) in late 2016 that took initial steps toward a unified, national regulatory framework for AVs. Then a year later, NHTSA issued *Automated Driving Systems 2.0: A Vision for Safety* that replaced the earlier policy framework (NHTSA 2017). It offered voluntary guidelines for the AV industry in designing best practices for testing and deployment of AV vehicles that incorporate SAE Levels 3–5 or highly automated vehicles. The policy framework did not carry a compliance requirement or enforcement mechanism. Instead, it offered suggestions on priority safety design elements and encouraged industry participants to perform voluntary safety self-assessments that demonstrate their approach to testing and deployment. It also clarified NHTSA versus states' responsibilities in this area. NHTSA regulates motor vehicles and motor vehicle equipment, while states are responsible for regulating the human driver and most other aspects of motor vehicle operation. In 2018, the U.S. DOT plans to release a third iteration of the guidance, AV 3.0. While the 2017 policy framework was focused on passenger vehicles, the 2018 policy guidance is expected to cover all transportation modes, including public transit, rail, commercial trucks, and aviation.

Federal regulatory action for CVs has focused on V2V technology, rather than V2I technology. In August 2014, NHTSA issued an advance notice of proposed rulemaking to begin implementation of V2V communications technology. Then in January 2017, NHTSA issued a proposed rule to establish new Federal Motor Vehicle Safety Standards to mandate V2V communications for new light vehicles and to standardize the message and format of the V2V transmissions. However, as of 2018 such rulemaking has not advanced. In November 2017, NHTSA issued a statement that it has not made any final decision on the proposed rulemaking concerning a V2V mandate.

In September 2017, the U.S. House of Representatives passed the SELF DRIVE Act, and the U.S. Senate followed by passing the AV START Act in October 2017. As of May 2018, Congressional action has not moved forward toward passage. These acts were in response to calls for regulatory changes at the federal level to promote the development of AV technology. Both acts preserve the existing differentiation of responsibilities between NHTSA and the states. The two acts take different approaches to privacy and cybersecurity. The SELF DRIVE Act provides that a manufacturer may not market a highly automated AV unless that manufacturer has developed a Privacy Plan and a Cybersecurity Plan that identifies, mitigates, and prevents privacy and cybersecurity vulnerabilities. The AV START Act establishes a Data Access Advisory Committee to produce a report to Congress with policy recommendations on ownership and control of data generated or stored by AVs. The AV START Act does require that manufacturers have a detailed plan for identifying and reducing cybersecurity risks.

State legislatures in the United States are becoming increasingly engaged on the topic of AVs. The National Conference of State Legislatures' (NCSL) Autonomous Vehicles Legislative Database provides current information on state legislative efforts (see http://www.ncsl.org/research/transportation/autonomous-vehicles-self-driving-vehicles-enacted-legislation.aspx.). According to NCSL:

- Forty-one states and Washington, D.C. have considered legislation since 2012, and
- Of those, 22 states and D.C. have passed legislation.

The states' legislation has been varied. Some states only enable testing, while other states enable use of an automated driving system on public roads and require a human driver should be in the test vehicles. A few states have recently updated their legislation to remove requirements that a human driver should be behind the wheel at all times. The legislation has been state-specific with no attempt at coordination across states, prompting the congressional action discussed previously that attempts to provide a national policy framework. As the technology for AVs continues to develop, state legislation will continue to evolve to address the potential impacts of these vehicles on the road.

In terms of a regulatory framework for shared mobility, state legislatures have been involved in regulating Transportation Network Companies (TNCs) and carsharing programs. As for other types of shared mobility, e.g., bikesharing, these are governed by local government regulations. For TNCs, as of August 2017, 48 states and Washington, D.C., have passed at least one piece of legislation regulating some aspect of TNCs (Moran et al. 2017). The amount and degree of regulation varies from state to state:

- Forty-three states and D.C. have laws that address operating permits and fees, background check requirements, operational standards, and protections for passengers.
- Five states have laws that address only insurance requirements for TNCs and TNC drivers.

A majority of state legislation includes preemption of the local authority to regulate, tax, or impose rules on TNCs. According to NCSL, a handful of states have enacted carsharing legislation. The legislation covers such issues as incentives to use carsharing, carsharing taxation, electrification of carsharing fleets, and creating a regulatory framework for peer-to-peer carsharing (see http://www.ncsl.org/research/transportation/car-sharing-state-laws-and-legislation.aspx).

European Union

In May 2018, the European Commission issued a Communication on an "EU strategy for mobility of the future" to harmonize the legal framework, research, and industrial innovation across Member States (European Commission 2018). In this strategy document, the European Commission put forth a progressive and harmonized approach to regulation of connected and automated mobility based on experience gained through demonstrations and large-scale testing to validate the safety of the technologies. It identified relevant automation use cases:

- Passenger cars and trucks at Levels 3 and 4 that are able to handle specific situations on the motorway (e.g., truck platooning convoys) and some low-speed situations in cities (e.g., valet parking) available by 2020.
- Public transport vehicles at Level 4 able to cope with a limited number of low-speed driving situations (e.g., urban shuttles for dedicated trips or small delivery vehicles) by 2020.
- The European Commission is linking policy and regulatory initiatives around these use cases. In addition the European Commission provides funding to support demonstrations and large-scale testing through Horizon 2020. In addition, it will provide support in 2018 for testing the use of 5G connectivity to enable highly automated driving functions and new mobility services. In the just-issued communication, the European Commission will intensify coordination with/among Member States so that traffic rules can be adapted to automated mobility in a harmonized way, such as with the 1949 Geneva Convention and the 1968 Vienna Convention on Road Traffic. As part of a revision of the General Safety Regulation for Motor Vehicles, the European Commission is also proposing to regulate:
- Data recorders for AVs to clarify whether the vehicle or a driver was in control during an accident,
- Platooning to ensure standardization of data exchange across different technologies, and
- Protection of vehicles against cyber-attacks.

The current European Commission strategy builds upon recommendations of the high level group (GEAR2030) that emphasized the need for a harmonized and cross-border regulatory framework for testing, communication, data security, safety, and cybersecurity (Government of Netherlands 2016). This document indicated that Member States will rely on a voluntary commitment of the industry to include connectivity in all new vehicles from 2019 onward. Therefore, no mandatory V2V or V2I regulation was envisioned.

Member States are also individually moving forward with regulation. There is a challenge to implement an EU-wide legal system considering the divergence of approaches among some Member States. For example:

- In 2016, France launched a decree regarding the testing of C&AV on public roads, which specified that by 2020, official standards to regulate tests would be operative.
- In 2016, Finland created a system of test plates and protocols for automated vehicle trials issued by the national transport safety agency, Trafi.

TABLE 1 Key Aspects of U.S. and EU Regulatory Frameworks for CAVSM

United States	European Union
2017: NHTSA issued voluntary guidelines for the AV industry in best practices for testing and deployment of highly automated passenger vehicles.	2018: European Commission communication to harmonize the legal framework, research, and industrial innovation across Member States.
NHTSA regulates motor vehicle equipment, while states regulate the human driver and motor vehicle operation.	European Commission is linking policy and regulations to use cases: (1) Levels 3–4 passenger cars and trucks on motorways and in cities, (2) Level 4 public transport vehicles in low-speed situations—both by 2020.
NHTSA rulemaking on V2V mandate has not advanced; neither has Congressional action in the form of SELF DRIVE Act (House) and AV START Act (Senate)—all in 2017.	2018: European Commission is providing support for testing 5G to enable highly automated driving and new mobility services. Voluntary commitment of industry to include connectivity in all new vehicles.
Since 2012, 22 (of 50) states and D.C. have passed automated vehicle legislation pertaining to testing and use on public roads. Legislation is state-specific, not harmonized.	European Commission intensifying coordination among Member States to harmonize traffic rules for automated mobility. EC proposing to regulate data recorders for AVs, platooning, and protection against cyber-attacks.
Forty-eight states have passed at least one piece of legislation regulating some aspect of shared mobility services.	Fragmentation of responsibilities for shared mobility among local, regional, and national entities.

- Under a broader digitalization initiative, in 2017, Estonia made it legal to test self-driven vehicles on all national and local roads in the country.
- Germany has no specific legal framework for the testing of automated vehicles, but testing in traffic is allowed with special permission.
- In Spain, national authorities have published a legal framework for public road testing that entails specific requirements for the application and granting of authorization for automated vehicle tests and trials on public roads.
- The United Kingdom (UK) is currently conducting a law review that includes the allocation of civil and criminal responsibility by law where there is shared control between humans and computers; the role of automated vehicles in public transport, carsharing and on-demand passenger services; the impact on other road users and how they can be protected from risk; and determining who the responsible person is in a self-driving vehicle.

However, the Member States have agreed to work transparently on the development of national legislation affecting consistent EU-wide deployment of C&AD. With a goal of consistency, the focus is on the role of the driver, the transfer of control from human to machine, and traffic behavior. Related, many Member States (except Spain and the UK) are signatories of the Vienna Convention, which makes it mandatory for a driver to be able to control the vehicle (Article 8). New amendments came into force in March 2016 (ETSC 2016a). The key amendment allows a car to drive itself, as long as the system "can be overridden or switched off by the driver." A driver must be present and able to take the wheel at any time. The interpretation in Member States' traffic codes has to still be adapted to enable Level 3—conditional automated driving. In Sweden, new legislation for trials has been proposed that enables testing on public roads as long as the manufacturer takes the responsibility.

While the European Commission has great interest in promoting sustainable urban mobility, such as different variations of shared mobility services, there is a fragmentation of responsibilities among local, regional, and national entities (Gudmundsson 2013). The European Commission has indirect tools at its disposal, either via the Member States or via the so-called soft-law. For example, in its announced Urban Mobility Package, the European Commission has requested the establishment of voluntary Sustainable Urban Mobility Plans, which will serve as a comprehensive planning tool for cities in the areas of land use, road charging and emission reductions, among others. It lacks enforcement power against those who will not comply with the plan. Technically, the European Commission could choose to impose mandatory measures on the Member States, which in turn will have to mandate and regulate cities. But this would raise significant governance challenges.

Over the past several years, the development of new technology has drastically changed how society functions. Mobile smartphones and online social networks are prime examples of technologies that have become ubiquitous in many people's lives. While these technologies have become invaluable to their consumers and citizens, they have also created a host of new data privacy and access challenges. A similar dynamic is playing out in the transportation sector in terms of CAVSM technologies. The next section highlights some of the important issues.

Data Privacy and Access

Key Takeaways

- CAVSM data enable individuals to be located in specific space and time. The more detailed the spatial location, temporal position, or individual information included in the data, the more privacy sensitive the data are and the greater the privacy risk.
- Innovations in computing, mobile devices, sensors, and global positioning systems have weakened traditional means of protecting PII.
- There are varying models of data access ranging from greatest ease of use (i.e., open access) to greatest privacy protection (i.e., restricted access).
- In the United States, there is no single comprehensive legislative framework for data privacy protection; instead, privacy protection relies on fair information practices. In the EU, data privacy is akin to a constitutional right.

Why Data Privacy and Access Are Important Socioeconomic Impact Issues for CAVSM

The paper's introduction defines and distinguishes the mobility technologies that are the focus of the EU-U.S. Symposium. The characteristics that they have in common are the collection, transmission, and application of large volumes of data.

- CVs receive and share data from onboard computers and sensors with manufacturers, other vehicles, other road users, infrastructure, and third-party service providers. These data relate not only to vehicle operations on the road and in-vehicle diagnostics, but also to users and their personal requirements. Data include location, driver behavior, biometrics, vehicle health, fuel consumption, vehicle emissions, personal communications, and infotainment selections (US Government Accountability Office 2017).
- AVs require extensive data to operate effectively. Their sensors and systems typically include: GPS for navigation; a wheel encoder for monitoring the movements of the car; radar on the front and rear bumpers for identifying traffic; a camera near the rear-view mirror for color identification; lane departure, read collision, and pedestrian alerts; and a lidar sensor on the roof used for generating a 3D map of the environment (Bloom et al. 2017). These sensors capture continuous data about the vehicle itself as well as the surrounding environment (i.e., people, vehicles, infrastructure within it).
- Most shared mobility services rely on smartphone apps or online platforms to connect paying travelers with the mobility fleets. Payment is often managed through the app or online platform, which stores credit card information. These services also have access to massive amounts of data on both the transport network (such as the current levels of speed and congestion), and on their passengers or clients (such as access/egress locations, routes taken, time of day and frequency of travel). The data are used for the internal optimization of the shared services, but they are also increasingly shared with third parties (Franckx 2017). Moreover, shared services can set up partnerships with cities and transport authorities in which data are integrated and shared for specific public services.

The unprecedented volumes and new types of data generated by CAVSM have the potential to improve safety, environmental outcomes, and accessibility; streamline movement of goods and people; and bring direct commercial benefit based on enhancing the consumer experience. Realizing these societal benefits, however, is contingent upon addressing data privacy and access issues.

Data Privacy

Data privacy is defined as the capability of individuals to "determine for themselves when, how, and to what extent information about them is communicated to others" (Westin 1967). This is particularly relevant to privacy of PII, which are any data that could potentially identify a specific individual, including any information that could be used to distinguish one person from another or that could be used for de-anonymizing anonymous data. There is no one list of what constitutes PII. Some examples of information that could identify an individual include name, address, date and place of birth, and biometric data as well as video data or GPS tracks of daily mobility. A single piece of data can be PII, such as a home address. Likewise, multiple pieces of data when merged can be PII, even when the individual pieces would not be.

Radical transformation of computing, mobile, sensor, global positioning, and database technologies have weakened traditional means of protecting individuals' privacy, leading to increasing risks associated with misuse of PII. Treatment of PII is distinct from other types of data because it needs to be not only protected but also collected, maintained, and disseminated in accordance with the fair information practices (in the United States) or according to regulations (in Europe). Balancing agencies' needs for using such data with individuals' concerns about their data privacy is a complicated challenge.

For example, according to a 2015 survey by the Pew Research Center, a majority of Americans believe it is important—often "very important"—that they be able to maintain privacy and confidentiality in commonplace activities of their lives (Madden and Rainie 2015). Most strikingly, these views are especially pronounced when it comes to knowing what information about them is being collected and who is collecting it. These feelings also extend to a desire to maintain privacy when moving around in public. Survey results from early 2015 show that 63% felt it was important to be able to "go around in public without always being identified." All adults, regardless of age or gender, express comparable views. Likewise in a 2015 survey to capture attitudes of EU citizens about issues surrounding data protection, two-thirds of respondents were concerned about not having complete control over the information they provide online (European Commission 2015). A majority were concerned about the recording of their activities via payment cards and mobile phones (55% in both cases). Most do not trust landline or mobile phone companies and internet service providers (62%) or online businesses (63%). Even though people are worried on their privacy, there is often an inconsistency between people's attitudes about privacy and their behaviors vis-à-vis social media and other digital platforms.

Data Access

Data access is directly associated with data privacy. Data access refers to a user's ability to retrieve data stored within a database or other repository. Entities that have data access can move, use, or manipulate the stored data. Rules for accessing data are critical in a Big Data environment because traditional approaches for privacy protection via informed consent and de-identification may no longer be effective (Kum and Ahalt 2013).

- *Informed consent* refers to permission granted by a person to participate in a data gathering activity with full knowledge of the possible risks and benefits of that participation. True informed consent is impossible when data are not knowingly provided by a person but result from an opportunistic sensing system. For example, how does one provide notice to individuals whose data have been collected via roadside Bluetooth® sensors?
- *De-identification* is a general term for any process of removing the association between a set of identifying data and the data subject (Garfinkel 2015). The term is often used interchangeably with anonymization. It attempts to balance the contradictory goals of using and sharing information about people with protecting their privacy. In recent years with increasing implementation of data science analytics, researchers have shown that de-identified data can often be re-identified through linkages among multiple datasets.

Kum and Ahalt (2013) identify varying models of data access that range from greatest ease of use to greatest privacy protection. These models are: open, monitored, controlled, and restricted. Examples of each of the models in CAVSM applications are noted below.

- **Open access:** Data are freely available online to all at no cost with limited restrictions as to reuse. Data are typically sanitized (i.e., standard disclosure limitation methods are applied) to allow public access. An example is advanced apps that employ open data, algorithms, and advanced programing interfaces (known as APIs) to aggregate real-time information services, multi-modal trip planning and fare payment into a single application, such as the Open Mobility Project in Berlin (see https://blog.bosch-si.com/mobility/intermodal-transportation-to-advance-mobility-in-urban-areas/).
- **Monitored access**: Access to data typically requires some type of user authentication, and the data are usually aggregated. An example is Uber Movement data where Uber makes its trip data available via a public website to users who request and receive approval to access it (see https://movement.uber.com/?lang=en-US).
- **Controlled access**: Access to data is controlled through the use of specialized software or a specialized platform. For example, specialized software is necessary to retrieve and analyze the data stored in Event Data Recorders (EDRs) (i.e., a vehicle's "black box") (Koch 2006).
- **Restricted access:** Access to information is restricted through decoupling, meaning that PII is separated out from sensitive data. An example of how vehicle data can be restricted is through blockchain technology. A simple description of blockchain may first be necessary. A "block" is a record of new transactions (e.g., a vehicle location, a mile traveled, a trip taken). Once a block is completed it is added to the "chain," creating a chain of blocks. The blockchains are interconnected such that each subsequent block contains a cryptographic image of the previous block. Thus data cannot be changed without recognition of that fact after the respective data have been entered into a block, completed, and "attached" to a subsequent block (Dorri

et al. 2017). Every block in the chain is linked to a published public key that represents a particular user. That key is encrypted so that the user cannot be identified. CAVSM use cases could include carsharing, ridesourcing, or CV-enabled road pricing schemes.

As described in the following section, the United States and Europe follow differing regulatory frameworks in terms of data privacy protection and data access control.

Privacy Protection

United States

The United States has a patchwork of federal and state laws and regulations that overlap, dovetail, and may even contradict one another (Jolly 2017). At the federal level, different privacy requirements apply to different industry sectors (e.g., health or financial information). The laws are often narrowly tailored and address specific data uses and users. An example is regulation pertaining to EDRs. EDRs store information produced immediately before and during an accident, such as date, time, vehicle and engine speed, steering angle, throttle position, braking status, force of impact, seatbelt status, and air bag deployment. None of these data elements are PII, but when combined with other technologies, such as onboard navigation systems or mapping apps, EDR data could be used to personally identify an individual (Canis and Peterman 2014). The Driver Privacy Act of 2015 provides that all car manufacturers must install EDRs, and all EDRs must collect specific information. It also stipulates that the EDR information belongs to the owner or, in the case of a leased vehicle, the lessee of the vehicle in which the EDR is installed. EDR data are restricted, accessed (via specialized software) and are shared only with the consent of the vehicle owner or lessee.

For those entities not subject to industry-specific regulation, the Federal Trade Commission (FTC) is the primary federal privacy regulator (Sotto and Simpson 2014). It uses Section 5 of the FTC Act, which is a general consumer protection law that prohibits "unfair or deceptive acts or practices in or affecting commerce" to bring privacy enforcement actions. Yet, in general, FTC enforcement has been mostly procedural, focusing on companies' notice and consent actions, such as ensuring that online companies have privacy policies, that the policies are not hidden in obscure places on company websites, etc.

Most states have enacted some form of privacy legislation. However, California leads the way in the privacy arena, having enacted multiple privacy laws, some of which have far-reaching effects at a national level, such as California's Confidentiality of Medical Information Act. Unlike many federal privacy laws in the United States, California's privacy laws resemble a European proactive regulatory approach to privacy protection. However, even in California, there is no regulatory framework that specifically addresses CAVSM data. Instead, there are many guidelines developed by governmental agencies and industry groups that are not legally enforceable but are part of self-regulatory efforts that are considered best practices in the context of CAVSM.

The automotive industry developed privacy principles in 2014 largely in response to data privacy and security concerns raised by U.S. Congressional members about the increasing connectivity and automation of automobile technology (Markey 2015). The auto industry privacy principles, effective for new vehicles manufactured no later than model year 2017, represent a unified response to such concerns (Alliance of Automobile Manufacturers and Association of Global Automakers 2014). Overall, the privacy principles require clear and prominent notices about the collection of information, the purposes for which it is collected, and the types of entities with which the information is shared.

Europe

Unlike in the United States, the right to privacy is a highly developed area of law in the EU. Until May 2018, the processing of personal data was regulated by the Data Protection Directive. This was an EU Directive adopted in 1995 that identified conditions under which personal data may be processed—transparency, legitimate purpose, and proportionality. This Directive has since been replaced by the General Data Protection Regulation (GDPR) that was approved by the EU Parliament in 2016, and it is subject to enforcement as of May 25, 2018.

It is important to note that GDPR is a Regulation and not a Directive. A regulation is a binding legislative act. It must be applied in its entirety across the EU, while a directive is a legislative act that sets out a goal that all EU countries must achieve. However, it is up to the individual countries to decide how to achieve the goal. Thus, the GDPR serves to harmonize data protection regulation across Member States (see https://www.eugdpr.org/key-changes.html). Its main goal is protection against privacy and data breaches. It covers "personal data" which is any information that can be used to directly or indirectly identify the person. Key provisions include the following:

- It applies to all companies processing personal data of data subjects residing in the EU Member States regardless of the company location or where the processing takes place.
- The request for consent must be given in an intelligible and easily accessible form, with the purpose for data processing attached to that consent request.
- Breach notification is mandatory, within 72 hours of awareness.

- Data subjects have the right to obtain confirmation as to whether personal data concerning them is being processed, where and for what purpose, as well as a copy of their personal data that is provided free of charge and in electronic format. They can also request that their data be erased and that processing of it cease.
- Privacy by design, which is a framework based on proactively embedding privacy into the design and operation of information technology (IT) systems, networked infrastructure, and business practices from the start of systems design, is a legal requirement.
- Breach of GDPR requirements can be fined up to 4% of annual global turnover or €20 million (whichever is greater).

While the United States and the European Union have privacy frameworks in place, there is no specific legislation or regulations that speak to the ownership and security of personal information generated or transferred by CAVSM.

As vehicles become increasingly connected, automated, and shared, so the volume of data they collect, combine, store and communicate increases. Complex questions arise as to whether such data constitutes "personal data" and, if so, who is responsible for it and how is it secured. While not all data collected by CAVSM will on its own identify an individual driver, passenger or user, in many cases it may be combined with other information to identify such individuals, and therefore it may be "personal data." For example, in the EU, location data collected by smartphones is generally considered to be personal data because individuals can be directly or indirectly identified through their patterns of movement. By analogy, geo-location data collected by CAVSM is likely to be considered personal data where this data alone or in conjunction with other information identifies an individual driver, passenger or user through their patterns of movement. The importance of the type of regulatory approach a nation follows is significant when considering that data emanating from connected, automated or shared vehicles constitutes PII.

TABLE 2 Key Aspects of U.S. and EU Privacy Regulation

United States	European Union
At federal level, data privacy protection provided by FTC consumer protection law that prohibits unfair or deceptive practices.	Data privacy akin to a constitutional right.
Most states have some form of privacy legislation; none address CAVSM data.	General Data Protection Regulation (GDPR) harmonizes data protection regulation across Member States.

CAVSM and Privacy Risk

CAVSM data enable individuals to be located in a specific space and time. The more detailed the spatial location, temporal position, or individual information included in the data, the more privacy sensitive the data are and the greater the privacy risk. Privacy risk is defined as a function of "the likelihood that a data action causes problems for individuals, such as loss of trust or economic loss, and the impact of the problematic data action" (Brooks and Nadeau 2015). Collection, retention, logging, generation, transformation, disclosure, and transfer are examples of data actions. One potentially problematic data action, for example, is surveillance in which personal data are used to track the activities and whereabouts of an individual in a way that may not be proportional to the service being provided. Some have suggested that an AV's sensors that scan the surrounding environment while operating on public roads equates to surveillance activity (Bloom et al. 2017). Two criteria are usually applied as a means of analyzing and categorizing use cases according to their privacy risk: likelihood of a problem and magnitude of harm (Zmud et al. 2016a).

Criteria 1—Likelihood of a Privacy Problem

The likelihood of a privacy problem occurring is the probability that a data action will generate a problem for the typical individual whose personal information is processed. Various factors associated with a particular use, as noted in Figure 1, will impact the probability of a privacy problem occurring.

Uses of CAVSM data that enable real-time applications raise fewer privacy concerns because personal data are not central to the use. In contrast, when data are retained or stored (instead of deleted) to analyze behavior, the privacy risk increases because the sensitive data could be involved in a problematic data action. Stored data simply allows more time for the data to be disclosed through an intentional or accidental data action. Second, if recurrent information about an individual's actions over time are amassed, that information may be used to track a person's whereabouts and activities. Both of these situations increase the probability of privacy issues. Other factors include the government versus third-party ownership of data, and the geographic comprehensiveness of the database.

Criteria 2—Magnitude of Harm from Privacy Problems

Privacy risk is a function of the magnitude of harm a data action creates, multiplied by the likelihood that the problematic data action occurs. The harm, or loss

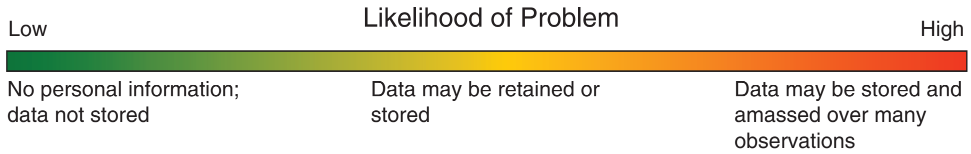

FIGURE 1 Relative likelihood of privacy problems.

incurred, due to a privacy problem may not always be straightforward to quantify. A data action that leads to financial losses such as credit card fraud, can be quantified in monetary terms. However, other losses may be ambiguous as agencies try to consider issues such as the effect of leaking embarrassing activity of individuals, variation of individual perceptions of privacy risk, and loss of public trust. The magnitude of harm from a potential privacy risk increases as CAVSM data are linked to other data sources (Figure 2).

There are three issues associated with CAVSM data that are related to greater or lesser privacy risk. These issues are open data, data sharing, and data ownership.

Open Data

Open data increases the likelihood of a privacy problem as well as the potential magnitude of harm. Open data is a concept that implies that data should be available to be freely used, re-used, and redistributed by anyone (see http://opendatahandbook.org/guide/en/what-is-open-data/). Many shared mobility platforms, such mobility-on-demand (MOD) rely on the availability open data. The value of open data is that it can be freely intermixed with other "open" material for an enhanced ability to combine different datasets together in order to develop more and better products and services. While some stakeholders call for open data in the interest of research and development across industries or public acceptance of connected and automated technologies, others are pursuing strategic partnerships or turning proprietary data into a business opportunity. The availability and flow of data becomes particularly important where that flow might enhance public safety or other interests.

In the United States, the Obama White House signed an Executive Order in 2013 making open and machine-readable the new default for government information with the goal of increasing citizen participation in government, creating opportunities for economic development, and informing decision making in both the private and public sectors. In 2014, the European Commission issued a directive establishing an open data policy in Europe (see https://joinup.ec.europa.eu/sites/default/files/document/2014-02/EU%20Open%20data%20policy.pdf). This policy stipulates that all publicly funded data must be available for all and must be easily combined with other types of open data (e.g., geo, traffic, tourism) to benefit EU-wide services and applications. In both the United States and Europe, the focus is on non-privileged data, that is, data which do not contain law enforcement information, national security information, personal information, or the disclosure of information that is prohibited by law. However, it should be noted that open data are mostly Big Data, whose value is increased through reuse, re-purposing, and linking to other sources. So open data increases the likelihood of a problem occurring and the risk for greater magnitude of harm. Open data standards are critical to ensuring privacy protection.

Data Sharing

Data sharing increases the likelihood of a privacy problem as well as the potential magnitude of harm. Because the value of data is maximized when different data sources are integrated, data sharing is becoming critical practice for both public- and private-sector agencies. For instance, private ridesourcing companies collect granular data (e.g., exact volume, time of day, O/D, length, speed) that can inform important urban and regional transportation planning or modeling issues. But, from the private-sector perspective, sharing this level of detail might jeopardize not only the individual's privacy but also the firm's business practices and intellectual property. Balancing these factors is a distinct challenge to public-/private-sector data sharing.

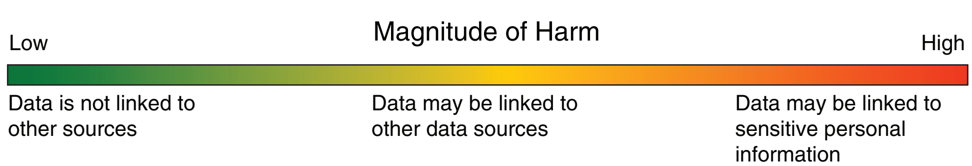

FIGURE 2 Relative magnitude of harm from privacy problems.

Data-sharing issues will only grow in importance as new transportation service models grow in stature. Again, drawing on the ridesourcing example, how does a local government in the United States adequately regulate this new industry without working with the same data as the regulated firm? As new models of service provision, such as CAVSM, appear on the horizon, the ability of public agencies to perform their regulatory roles is called into question unless all sides agree on common data-sharing principles. A possible solution is data sharing via a data exchange, such as the World Bank's OpenTraffic project (Zipper 2018). It was initially developed as a way to aggregate traffic information derived from commercial fleets. In 2017, the project became a part of SharedStreets, a collaboration between the National Association of City Transportation Officials (NACTO), the World Resources Institute, and the OECD's International Transport Forum to pilot new ways of collecting and sharing a variety of public and private transport data. It goes beyond open data and is attempting to develop ways for working with privacy sensitive data, such as collecting aggregated data that is rich enough to allow for deep analysis while still hiding information about individual rides. Still there are challenges in incentivizing private-sector partners like Google, Uber, Lyft, Didi Chuxing, Ofo, and Mobike to participate. Without such a majority of entities in a city or region participating, data availability will affect not only the quantity but also the quality of information that is available for more and better mobility products and services.

Data Ownership

Data ownership determines whether a privacy problem is likely to happen. Ownership of data is tantamount to control, determining who can collect, process, use, and disseminate data. Ownership also implies who can profit from what is owned. CAVSM data hold significant monetization potential, whether it is vehicle diagnostics data (like speed, tire pressure, etc.) or data regarding customer opinions and driving experiences. For example, McKinsey & Company has estimated that the car data market could generate as much as $750 billion in revenues by 2030 (Alonso Raposo et al. 2018).

Ownership is straightforward when applied to a house since there is a formal transaction with written acknowledgment that makes ownership clear. However, when applied to data, ownership becomes complicated. There are many roles with which the notion of owner could be associated, from the data creator, to the data packager, to the data subject. However, just as important, ownership implies a broader responsibility—data stewardship—where the owner must consider the consequences of how the data are used, particularly for how a particular use might impact data privacy. In the United States, the concept of data stewardship is rooted in a rather loose approach to data governance that solely reflects fair information practice as defined by the FTC (Diamond et al. 2009). In Europe, on the other hand, the GDPR specifically sets requirements on organizations' data governance and enforces these requirements with financial sanctions. These requirements include issues of data quality and assurance of that quality. The key requirements of GDPR's Article 5 involve appropriate usage, accuracy and data security. Specifically, it mandates that "every reasonable step must be taken to ensure that personal data that are inaccurate, having regard to the purposes for which they are processed, are erased or rectified without delay." Under GDPR, it will be important to do validation at both the time of data collection/entry and at time of use.

Safety and Security

Key Takeaways

- The "traffic crash" externality reflects the *social cost* of driving that are costs inflicted on fellow road users and spillover effects on the rest of society (such as congestion costs).
- Drivers, vehicles, and environmental conditions can all cause crashes. However, human errors are a critical cause of more than 90% of crashes.
- In the United States CV applications are mostly seen as bringing safety benefits. In Europe, environmental and traffic flow benefits are also cited, and V2I technologies are viewed as fundamental to smart mobility applications.
- The more miles/kilometers that AVs travel on different roads, in different environments, and under various weather conditions, the more quickly their safety improves and their capability to monitor the surrounding environment increases.
- Trust in AV technology is a barrier to acceptance and use.
- While cybersecurity issues are a challenge for CVs, security becomes a bigger concern with Level 4 and Level 5 AVs, in which software and connectivity play a much bigger and more critical role for safe driving.

This chapter discusses two inter-related cross-cutting issues: safety and security. Safety often refers to road traffic safety, which is defined as the reduction in harm (deaths, injuries, and property damage) resulting from collisions involving vehicles and/or people traveling on public roads. The most common measures to define road safety are the number of road crashes, the number of road casualties, and the associated negative consequences (Wegman 2017). Traffic safety benefits are a fundamental motivator for CAV development and deployment. Closely related to safety is the topic of security. Up until recently, vehicle security was related to anti-theft or hijacking measures. But current interest in security stems from the convergence between automotive technology and computer technology that has increasingly changed the methods by which motor vehicles are developed and are driven. The introduction of telematics, connectivity, and the integration of smartphones and Bluetooth devices makes vehicles vulnerable to cyber-attacks (IEEE 2018). There is also concern about the security of personal data collected and stored in shared mobility databases, as discussed in the previous chapter.

Why Safety Is an Important Socioeconomic Impact Issue for CAVSM

When people drive a vehicle, they not only increase their own risk of a crash, but also increase crash risks for other motorists, as well as pedestrians and bicyclists. This consequence of driving is known as the "traffic crash" externality. It reflects the *social cost* of driving, which is conceptually different from the private costs individuals may incur, such as injury, death, or damage costs. Motorists can internalize these private costs by refraining from driving, exercising greater care while driving, or insuring themselves (and vehicles) against possible damages (Jansson 1994). But some traffic crash costs are not internalized by the motorist. There are costs inflicted on fellow road users and spillover effects on the rest of society (e.g., congestion costs, net output losses, and hospital treatment). In such cases, the total costs of the crash are not borne just by the individuals involved (Edlin and Karaca-Mandic 2006; Parry et al. 2007; Anderson et al. 2014).

In 2016 in the United States, there were 37,461 people killed in motor vehicle crashes, an increase in lives lost from 2015 and 2014 (respectively, 35,092 and 32,657) (NHTSA 2016). Crash risks are not limited to occupants or operators of motorized vehicles. Of the more than 2 million roadway injuries in the United States in 2011, 69,000 were pedestrians and 48,000 were bicyclists (Anderson et al. 2014). NHTSA estimated the total social cost of motor vehicle crashes in the United States in 2010 as US$242 billion (NHTSA 2015a). The cost components included productivity losses, property damage, medical costs, rehabilitation costs, congestion costs, legal and court costs, emergency services, insurance administration costs, and employer costs.

In Europe, unlike in the United States, road fatalities are declining. In 2016, 25,500 people were killed. The European Commission estimated the social cost of these road fatalities and injuries to be at least €100 billion (Traffic Impact Newswire 2016). The 2016 fatality estimate was 600 fewer than in 2015 and 6,000 fewer than in 2010, and it represented a 19% reduction over the last six years (European Commission 2017a). However, not all Member States have had improvements in road safety since 2010. The countries with the lowest fatality rate per million inhabitants were Sweden, the UK, the Netherlands, Spain, Denmark, Germany, and Ireland.

Causes of Traffic Crashes

Drivers, vehicles, and environmental conditions can all cause crashes. However, human errors are a critical cause of more than 90% of crashes at the national level in the United States (NHTSA 2015b).[1] While a comparable statistic could not be found for the European Union in aggregate, the U.S. statistics were often cited and applied to a European context (see for instance, https://ec.europa.eu/transport/themes/its/road_it). The attribution of critical reasons by NHTSA are presented below and are assumed to apply reasonably well to Europe:

- Drivers, 2,046,000 crashes (94%);
- Vehicles, 44,000 crashes (2%);
- Environment, 52,000 crashes (2%);
- Unknown, 47,000 crashes (2%).

The driver-related "errors" are broadly classified into: recognition (41%), decision (33%), performance (11%), and non-performance (7%) errors.

- Recognition errors include those related to a driver's inattention, internal and external distractions, and inadequate surveillance. Such errors would include the broad category of distracted driving (NHTSA 2015a).
- Decision errors include driving too fast for conditions or too fast for curves, and making false assumptions of others' actions or illegal maneuvers. Alcohol involved crashes involve both impaired judgment (decision errors) and perception problems (recognition errors).

[1] The "critical cause" is defined as the immediate reason for the pre-crash event as collected in NHTSA's National Motor Vehicle Crash Causation Survey, conducted from 2005 to 2007.

- Performance errors include overcompensation, poor directional control, etc.
- Sleep (or drowsy driving) was the most common critical reason among non-performance errors.

In NHTSA's National Motor Vehicle Crash Causation Survey, vehicle-related factors were identified primarily as problems with: tires, brakes, steering column, etc. Environment-related causes were defined as roadway or atmospheric conditions.

Impacts of CAVSM on Traffic Crashes

CV Technologies

Safety messages provided by V2V and V2I technologies should enable drivers or automated vehicle systems to take actions that could reduce the severity of traffic crashes or avoid them. Such messages simply warn the driver (in the case of non-highly automated CVs) when there is high risk for collision but do not automatically apply the brakes. Their effectiveness depends upon drivers having the applications in their vehicles, turning them on, and paying attention to the warnings.

Much of the early evidence about effectiveness of V2V or V2I applications in mitigating traffic crashes is from computer-based simulations. Najm and others (2010) found V2I systems bring only small marginal benefits to the safety benefits of V2V systems alone. The U.S. Government Accountability Office (2013) pointed out that organizations researching the benefits of V2V or V2I have noted that the benefits depend on a variety of factors, including the size and location of the deployment, the number of roadside units deployed, the types of applications that are deployed, and that some applications require a majority of vehicles on the road to be equipped before reaching optimum safety benefits.

In the United States, development and testing has shifted in the last several years to focus more on V2V applications. This was to facilitate the implementation of safety technologies that do not require state and local governments to make costly infrastructure investments. Also, this shift was in response to what was considered to be impending NHTSA rulemaking on V2V. As noted earlier, NHTSA has since delayed its decision. But at the time, NHTSA and FHWA through the ITS/JPO Joint Program Office began focusing on evaluating the technical strengths and weaknesses of V2V. A study of V2V devices installed as part of the Connected Vehicle Safety Pilot Model Deployment in Michigan found that the devices were technically able to transmit and receive messages, and safety applications enabled by these devices were effective in mitigating potential crashes (Harding et al. 2014). But it also noted that various aspects still needed further investigation including: the impact of spectrum sharing, ability to mitigate V2V communication congestion, incorporation of GPS positioning to improve relative positioning, remedies to address false positive warnings, and driver-vehicle interface performance.

More extensive evaluative data on the effectiveness and benefits of specific applications is expected from the Connected Vehicle Pilot Deployment programs in New York City, Tampa, and Wyoming that are currently underway and expected to be completed by 2021. These pilots will also assess the potential negative consequences of safety warnings, such as driver distraction.

- The New York City pilot aims to improve the safety of travelers and pedestrians by testing and evaluating V2V and V2I vehicle applications and V2I pedestrian applications. The pilot will equip taxis, Metropolitan Transportation Authority buses, United Parcel Service vehicles, NYCDOT fleet vehicles, NYC Department of Sanitation vehicles, and pedestrians (see https://www.its.dot.gov/factsheets/pdf/NYCCVPliot_Factsheet_020817.pdf).
- The Tampa pilot aims to improve the safety and mobility of automobile drivers, public transit riders, and pedestrians by also testing and evaluating V2V and V2I vehicle applications and V2I pedestrian applications. This pilot will equip privately owned vehicles, buses, streetcars, and pedestrians (see https://www.its.dot.gov/pilots/tampa_participants.htm).
- The Wyoming pilot aims to improve driver safety along Interstate 80 by testing and evaluating V2V and V2I applications that provide advisories, roadside alerts, and dynamic travel guidance. The pilot will equip 400 fleet vehicles and commercial trucks (see https://www.its.dot.gov/pilots/pdf/04_CVPilots_Wyoming.pdf).

Unlike in the United States where CV applications are mostly seen as bringing safety benefits, in Europe CV applications are also seen as enabling important environmental and traffic flow benefits. In addition, V2I technologies are viewed as fundamental to smart mobility applications much more so than in the United States, where a viable business case for V2I is still being discussed.

Significant cross-border CV research and development activities underway in Europe include the following:

- Following an agreement between the German, Dutch, and Austrian transport ministries, the relevant highway operators and partners from the automotive industry have launched a cooperative C-ITS corridor from Rotterdam to Frankfurt am Main to Vienna. It will be deployed gradually and enables the exchange of traffic information between vehicles and the roadside infrastructure and information flows among vehicles equipped with cooperative systems (see http://www.itsinternational.com/categories/networking-communication-systems/features/tri-nation-cooperation-on-c-its-corridor/).

- C-Roads is an open platform created by the European Commission and Member States to develop harmonized specifications for C-ITS. It was to start developing interoperability validation tests by fall 2017 (see https://www.c-roads.eu/platform.html).
- NordicWay is a C-ITS corridor project between Finland, Sweden, Norway, and Denmark. The project will develop a V-shaped corridor linking Oslo, Gothenburg, Copenhagen, Stockholm, and Helsinki. NordicWay is focused on demonstrating the concept of C-ITS via cellular 3G and 4G/LTE communication, and it will involve about 2,000 equipped vehicles (see Nordicway.net).
- UKCITE (UK Connected Intelligent Transport Environment) is a collaborative project between vehicle manufacturers, communications companies, academia and local authorities to create a 40 miles of urban and inter-urban roads equipped with LTE, ITS-G5 and WiFi to investigate their use in V2X applications to reduce congestion, provide entertainment and deliver improved safety performance (see https://www.cwlep.com/news/uk-cite-project).

AV Technologies

Safety is a primary motivation for AV development in both the United States and in Europe. As more of the driving task is switched to the automated driving system with SAE Levels 3–5, AVs should mitigate a significant portion of the crash risk stemming from human error. This benefit is cited even subsequent to four known AV fatalities since 2016. Safety (or trust in the technology) has also been cited by several studies as an influencing factor in public acceptance and adoption of AVs (Zmud et al. 2016b, Smith and Anderson 2017, Kolodge 2017, Sener et al. 2018). Unlike the hands-off, market-driven regulatory approach that is the norm in the United States, European countries have taken a much more public-safety-oriented approach. Still, several countries in Europe have welcomed automated vehicle tests on their public roads. Deployers of the technology need permission, but the procedure may be relatively simple, as in Finland: https://www.trafi.fi/en/road/automated_vehicle_trials.

Continuing to test AVs on public roads is critical to development. The machine learning algorithms that govern AV performance currently rely largely on experiencing various road conditions and situations. Current common belief is that the more miles/kilometers that AVs travel on different roads, in different environments, and under various weather conditions, the more quickly their safety improves and their capability to monitor the surrounding environment to enable observations of other road participants, etc., improves. But since vehicles at SAE Levels 3–5 are not yet on the market, those miles are not accumulating very quickly. Validation methods are ongoing research topics.

Evidence on AV performance vis-à-vis a human driver is sparse. One recent study in the United States compared, via simulation, AV crash rates to data from the Strategic Highway Research Program (SHRP) 2 naturalistic driving study (NDS) (Blanco et al. 2016). The research found that self-driving cars in automated mode had significantly fewer crashes than conventional vehicles; however, results were caveated because of the low exposure of self-driving vehicles (about 1.3 million miles in the study) compared to the SHRP 2 NDS (over 34 million miles). In another study, Kalra and Groves (2017) modeled and compared two scenarios: (1) AVs are publicly available for early purchase when *slightly* safer than human drivers and (2) when market availability is delayed until AVs are *nearly* perfect. They found putting vehicles on the road sooner (even if not perfect) can save more lives and improve vehicle performance more quickly than waiting for perfection.

Other research has indicated that AVs could address several of the key causes of traffic crashes.

- **Recognition Errors**. For AVs, the impacts on recognition errors vary by level of automation. For Level 3, the automated driving system monitors the driving environment and is in control of the driving task. It may request intervention from the human driver at any time, particularly in dangerous situations (e.g., unusual traffic patterns or inclement weather). Much research suggests that this task switching is difficult to do and may exacerbate crash risk (Jannsen and Kenemans 2015; Trimble et al. 2014). At Levels 4 and 5, the automated driving system assumes all aspects of the driving task and does not expect a human driver to intervene. We can expect these vehicles could reduce crashes caused by human recognition errors. But the automated driving system is learning from the driving it experiences as an iterative process. It is basically learning from itself, and so may not know how to behave in unknown situations. In some cases the response may lead to a crash. For example, analyses of accident reports filed by different AV manufacturers testing in California indicated that the most frequent accident was rear-end collisions, happening with a frequency that is double that of conventional cars (Favarò et al. 2017). Interestingly, research has indicated that a Level 2 technology (i.e., autonomous emergency braking (AEB) technology in current model passenger vehicles) led to a 38% overall reduction in rear-end crashes for vehicles fitted with AEB compared to a comparison sample of similar vehicles (Fildes et al. 2015).

- **Decision Errors.** AVs in control of the driving environment (Levels 4–5) that obey traffic laws may reduce decision errors. At Level 3, the driver would remain in control of the driving task and thus, still be in a position to make decision errors or to disobey or misuse the system.
- **Performance Errors**. At high and full automation (Levels 4, 5), the automated driving system is in control of the driving task and performance errors could be reduced in many situations. However, there is the possibility of overreliance on the automated driving system or driving skill degradation. This is also true for lower levels of automation. This was in fact what the U.S. NTSB found in its investigation into a fatal Tesla crash in May 2016, saying that a probable cause was the driver's inattentiveness due to overreliance on Autopilot (currently a Level 3 technology) (Bhuiyan 2017). Tesla has since modified Autopilot to warn drivers more frequently to keep their hands on the steering wheel. After three warnings, the system cannot be engaged without stopping and restarting the car. Tesla has also modified how Autopilot's radar and camera sensors interact to improve the vehicle's ability to recognize obstacles (Boudette and Vlasik 2017).
- **Non-Performance Errors**. Sleep was the most common critical reason among non-performance errors. A sleeping driver might experience a performance gap in taking over the wheel of a Level 3 AV. When designing for higher levels of automation, a driver should expect to be able to sleep, to enable a high probability of enhanced safety. At Level 3, sleeping would be misuse of the AV.

An EU Horizon 2020 project, ADAS&ME, is currently evaluating how the use of C-ITS and automated safety functions, together with unobtrusive driver monitoring, can compensate for human errors such as those discussed above.

AVs might introduce new errors as more of the driving task is switched to the automated driving system; many technologies (i.e., sensors, motion control, trajectory planning, driving strategy, situational awareness, etc.) need to operate effectively so that the vehicle performs at least as well as a human driver (Trimble et al. 2014). New types of vehicle errors could stem from premature release of hardware or software as in the Tesla Autopilot example or inadequately maintained vehicles by owners (private, fleet) or manufacturers. Also, the safe operation of AVs in adverse weather conditions is uncertain (Boston Consulting Group 2015). Snow might cover lane markings so these are not readable by lidar and cameras mounted on vehicles. Snow, frost or ice covering the sensors also causes problems, not only when they cover the lane markings. Heavy rain might damage the lidar mounted on a car's roof, causing technology failure.

While automated driving may introduce new types of driving behaviors and new crash morphologies, it should be the case that the causes of collisions involving automated vehicles can be well characterized through recorded sensor data. Early research suggests that AV technologies have *promise* in mitigating traffic crashes, but their safety benefits are not guaranteed. Testing of the technologies is necessary for establishing safe operations. In Europe, many new testing activities and demonstration projects at the national and European level are emerging. Examples of the test implementations in Europe include the following:

- CoEXist (i.e., AV-Ready' Transport Models and Road Infrastructure for the Coexistence of Automated and Connected Vehicles) funded under H2020, aims to increase the knowledge of road authorities in transitioning toward a shared road network with increasing levels of AVs using the same road network as conventional vehicles. The project entails: (1) transport modeling, (2) tool building, and (3) simulated use cases in four road authorities (Gothenburg, Helmond, Milton Keynes, and Stuttgart, see https://www.h2020-coexist.eu/).
- Volvo DriveMe Pilot is deploying 100 Volvo XC90s in the first deployment of a Level 3 automated driving system on public roads with non-professional test drivers. The vehicles, equipped with a beta version of Volvo's IntelliSafe Autopilot are provided to real-world users for typical commuting and daily use (see https://www.testsitesweden.com/en/projects-1/driveme).
- L3PILOT is a large-scale test started in September 2017. It is unique due to its size (EUR 36 million EU-funding) and is the first in the world to test such a comprehensive array of different automated driving functions for passenger cars. L3PILOT involves 34 partners including 13 Car Manufacturers a large number of systems and component suppliers and leading universities and research institutes. Trials will be carried out in 11 European countries, with 100 vehicles and 1000 test drivers. The tested functions cover a wide range from parking to overtaking, and urban intersection driving (see www.l3pilot.ue/index.php?id=26).
- AUTOPILOT is a large-scale pilot project started in January 2017 focusing on the autonomous vehicle

in a connected environment, enabling the emergence of connected ecosystems supported by open technologies and platforms. The 5GCar started in June 2017 as a large research and innovation project developing the 5G connectivity technologies for automated cars and will evaluate the existing and future spectrum usage for that purpose and contribute to the standardization efforts in the field (see https://cordis.europa.eu/project/rcn/206508_en.html).

- Truck platooning is the term used to describe trucks using connectivity and automation to follow each other at a very short distance to save fuel and reduce CO_2 emissions. The ENSEMBLE project (EUR 20 million EU-funding) will start in summer 2018 and will support the standardization of communication protocols for multi-brand platooning by 2021. The study led by TNO will see collaboration among the six major European truck manufacturers (Daf, Daimler, Iveco, MAN, Scania, and Volvo). See http://ec.europa.eu/research/participants/portal/desktop/en/opportunities/h2020/topics/art-03-2017.html.
- In the next years, more large-scale demonstration pilot projects to test highly automated driving systems for passenger cars, efficient freight transport operations and shared mobility services in urban areas, funded under "Horizon 2020" can be expected.

The UK Department for Transport has the stated aim of getting driverless cars on the roads by 2021. Three deployment-pilot projects funded by Innovate UK are currently ongoing. The GATEway project is validating a series of different use cases for AVs, including driverless shuttles and automated urban deliveries on the Greenwich peninsula; UK Autodrive is deploying self-driving pod cars in pedestrian zones in Milton Keynes and Coventry; and Venturer is currently moving from simulator studies to applied experiments in real vehicles in controlled environments in Bristol and the South Gloucester region (Dennis and Spulber 2017).

In the United States as of February 2018, testing of SAVs on public roads is through 17 active pilots in eight states (Stocker and Shaheen Forthcoming). The states are California, Arizona, Washington, Michigan, Pennsylvania, Florida, Texas, and Massachusetts by companies such as Waymo, Uber, Easymile, Ford, Navya, Cruise/GM and Drive.ai. After the fatality caused by an Uber vehicle in Arizona in March 2018, Uber suspended testing in North America. The majority of these pilots are targeting Level 4 technology in which a human operator does not need to control the vehicle as long as it is operating in a suitable operational design domain given its capabilities. They are operating as one of two types: (1) on private roads and in planned communities and (2) on public roads and city streets.

Shared Mobility

As with CAVs, shared mobility operations have the potential to both mitigate and exacerbate human-error caused traffic crashes. In terms of the former, shared mobility operations could mitigate traffic crashes by providing an alternative to driving for some at-risk drivers. Driving under the influence of alcohol (DUI), or impaired driving, is a major contributor to crashes and fatalities on roadways. Proponents argue that ridesourcing services offer a safe transportation option for individuals who have been drinking, particularly among young adults, who are both more frequent users and a segment of the population that may drive while impaired (Elgart et al. 2016). However, research in this area is scarce. While anecdotal evidence suggests that ridesourcing is being used by individuals who go out drinking, formal research lacks data to attribute reductions in impaired driving and improved safety to any one factor, such as ridesourcing services (Shirgaokar 2016).

In terms of exacerbating crash risk, increased congestion at the curbside not only increases the potential for vehicle crashes but also for crashes with other road users (Rogers 2017). The "curb" is home to bikesharing programs, cycling lanes, ridesourcing passenger pick up and drop off, and goods delivery. Some cities have also set aside curbside space for carsharing services. As such, curb management for congestion and safety has become a priority for many cities. We should note than in addition to congestion and safety issues, there are equity issues pertaining to the use of curbside space for a private business or non-profit purpose, as well as for competing operators and modes (Shaheen et al. 2016). As of yet, curbside management for congestion caused by ridesourcing or increased goods delivery operations does not appear to be as widespread an issue in Europe as it is in the United States.

Personal security concerns have been raised about many innovative mobility services, as they have been historically for the conventional for-hire industry (Transportation Research Board 2016). Incidents involving safety of passengers receive intense media attention, although little research has actually documented the prevalence. However, ridesourcing technologies (and similar apps being adopted by the taxi industry) may mitigate risks to passengers and drivers by documenting the details of trips and removing anonymity, as may the cashless transactions made possible through ridesourcing or mobility-on-demand billing systems. In the United States, many local authorities and municipal, regional, and state governments are reviewing public safety regulations for ridesourcing and other shared mobility services. For example, much attention has been given to the inconsistencies between the background checks applied to taxi versus ridesourcing drivers and of different vehicle inspection requirements for the two types of services.

Trust in AV technology is a barrier to acceptance and use. So a question of interest is what is the influence of the absence of a driver in autonomous ride-hailing vehicles? There is sparse research on the topic. A Kelly Bluebook survey (2016) found that respondents preferred using ridesourcing services with human drivers to using them as self-driving vehicles (respectively, 56% vs. 44%). But among current ridesourcing users, there was a preference for using them as self-driving vehicles (51% vs. 49%). That study prompted another study that tested the hypothesis that current ride-hailing users will be early adopters of automated vehicles (Sener et al. 2018). This latter study also found that current ridesourcing users would be almost twice as likely to accept and use automated vehicles as non-users.

Will there be many single occupancy trips or more high occupancy trips? With these services, a driver may pick up more than one rider going in the same direction. Most frequently cited reasons for this were inconvenience and discomfort associated with riding with strangers, especially in the absence of a designated driver.

Why Cybersecurity Is an Important Socioeconomic Impact Issue for CAVSM

Cybersecurity—in the context of vehicle systems, refers to security protections for systems in the vehicle that actively communicate with other systems or other vehicles (Bryans et al. 2017). While cybersecurity issues are a challenge for CVs, security becomes a bigger concern with Level 4 and Level 5 AV vehicles, in which software and connectivity play a much bigger and more critical role for the safe driving of vehicles. Unlike traditional vehicles, AVs may be vulnerable to cyber-attacks that can spread from vehicle to vehicle, which may constitute a new type of safety threat. In the case of a cyber-attack the safety of passengers in an AV and other road users could be at risk. In a case of hacking and stopping a fleet of AVs, the transportation system could be halted with potential safety reduction (even though no real case of *malicious* car hacking has been reported yet). Miller and Valasek (2015) exposed the security vulnerabilities in automobiles by *unmaliciously* hacking into cars remotely, controlling the cars' various controls from the radio volume to the brakes. All entry points into the vehicle, such as Wi-Fi, the OBD-II port, and other points of potential access to vehicle electronics, could be potentially vulnerable to real-time intrusion (hacking) that could affect the mechanical operation of the vehicle. A large number of vehicles communicating to/with each other is essentially an ad hoc, self-forming network of devices with no server-side security (McCormick 2017). Cybersecurity, therefore, is a new factor that shapes the existing crash externality. Since a very small percentage of accidents are caused by mechanical errors, this should have little actual negative consequences in terms of the safety benefits of CV or AV technologies, as the $1.2 billion Toyota settlement, after a four-year criminal probe into its handling of a spate of sudden accelerations in its vehicles, highlighted. However, one major high-profile mechanical failure of an AV could have profound implications for technology deployment.

Security by Design, Standards, and Legislation

The U.S. DOT has adopted a "security by design" principle as it develops the system architecture for connected vehicles–meaning that cybersecurity systems will be built in from the start. When people speak of security by design, they often refer to a broad spectrum of activities and approaches used to build stronger security. "Spectrum" is an accurate term for this concept, as it spans lifecycle activities and functional domains, i.e., consideration of requirements, definitions, design, development, testing, and maintenance. Cyber solutions need to be developed in the context of security vehicles not just adopted from other industry sectors (Kitayama et al. 2014). While the end-to-end security design problems for the IT industry have been developed, these are not necessarily applicable to vehicles. There are significant differences between securing IT equipment (such as servers and PCs) and securing vehicles. One of the main differences is that with vehicles human safety is a primary design consideration. In addition, the lifecycle of a vehicle is often much longer than the lifecycle of many PCs and related IT equipment.

While the U.S. DOT promotes the security by design concept, there is only voluntary best practices guidance on vehicle cybersecurity. There are also industry standards being developed through the SAE. These include SAE J3101–Hardware protected security for ground vehicle applications and SAEJ3061–Cybersecurity guidebook for cyber-physical vehicle systems.

On the other hand, in Europe there is EU-wide legislation on cybersecurity (Directive on Security of Network and Information Systems) that was adopted by the European Parliament in August 2016. Member States were required to transpose the directive into their national laws (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52017XX0720%2801%29). Among other measures, Member States are required to set up a Computer Security Incident Response Team and a competent national NIS authority to promote swift and effective operational cooperation on specific cybersecurity incidents and sharing information about risks. Businesses in sectors that are identified by the Member

States as operators of essential services have to take appropriate security measures and notify relevant national authorities of serious incidents. Also key digital service providers (search engines, cloud computing services and online marketplaces) have to comply with the security and notification requirements under the new directive.

Economics and Workforce Issues

Key Takeaways

- Access to opportunities, underpinned by mobility, is a key enabler of prosperity that can be enhanced by new services facilitated by connectivity and automation.
- Driven by the potential for operational efficiency, organizations are exploring opportunities for CVs and AVs in long haul trucking operations and urban deliveries.
- A proliferation of connected, automated (as trials) and/or shared passenger transport services have emerged, particularly in cities in both the United States and the European Union.
- This could have a range of impacts including changes to mode choice, acceptability of trip length, land use values, accessibility of employment, retail and congestion impacts.
- While new jobs may be created in the operation and development of CV and AV services, there is a high likelihood of job losses from driving-focused roles.
- Given these societal impacts, it will be important that regulatory authorities are aware of these impacts and can act to maximize the benefit and minimize harm from the proliferation of CAV services.

The development and deployment of CAVSM is underpinned by envisaged safety and efficiency benefits. However, CAVSM will not flourish without also delivering sound economic returns. Innovation in CAVSM technologies is also creating opportunities for new forms of transportation to emerge. These have the potential to alter significantly the number and types of jobs associated with the movement of people and goods. This section therefore explores the socioeconomic impacts of CAVSM on economics and the workforce in the United States and the European Union.

Why Economics and Workforce Are Important Socioeconomic Impact Issues for CAVSM

Whether it is the movement of goods from manufacturer to marketplace, material to the manufacturer, or the movement of employees from home to office, mobility is directly associated with economic prosperity (e.g., Eddington 2006). The introduction of CAVSM services could influence the availability, cost, and efficiency of mobility services with an associated impact on local, regional, and national prosperity. The ways in which CAVSM services are deployed and operated may have differential impacts on how the benefits of automation are distributed.

In addition, the presence or absence of connectivity may shape where CAVSM services can be deployed successfully. The use of robots is often linked to improving efficiency by tackling tasks that exhibit one or more of the three 'D' characteristics: dull, dirty, and dangerous (Murphy 2000). Automation of driving can therefore increase the efficiency of transport by providing safer, more reliable transportation. However, task automation is typically associated with a reduction in the number of employees and/or the training required to deliver that task. This is especially true when an employee represents a significant element of the operating costs for that system. For a taxi in Zurich, a driver is estimated to represent 88% of the operating costs of the vehicle (Bösch et al. 2017); for a bus in Zurich, the driver is estimated to represent 55% of the operating costs of the vehicle (*Op. cit.*); while the average marginal costs for a truck driver in the United States are estimated to represent 43% of the operating costs of the vehicle (Hooper and Murray 2017). Consequently, there are significant economic efficiencies to be achieved if an automated system could replace the driver and for use cases where there is economic benefit, the switch may happen rapidly. However, it is over-simplistic to assume that all costs associated with the driver would be saved by introducing automated vehicles. The purchase/leasing and maintenance of these vehicles would represent a greater expense than traditional vehicles while other challenges to business models may emerge as roads authorities learn how to manage the deployment of automated vehicles effectively.

A typical car spends the majority of its life static, with use at less than 5%. The ability to share vehicles, either by having a single vehicle serve multiple individual customers sequentially or by pooling individuals taking similar journeys into a single vehicle, could increase vehicle use and thereby unlock previously unattainable efficiency benefits. The prerequisite is that these services are attractive and accessible enough to be used. Shared vehicle services are made feasible by connectivity (enabling users to find rides with others traveling to the same or nearby destinations) and can potentially be made more efficient by automation (by reducing the operational costs and increasing operational flexibility of the shared vehicles) (Greenblatt and Shaheen 2015).

Freight Transport

The movement of goods is often cited as a low-margin activity (e.g., Caballini et al. 2017). As a result, improvements in efficiency are aggressively pursued with the freight sector pushing innovations in connected vehicle and goods tracking technologies. Automation of the driving task is attractive for the industry to reduce the economic cost and physiological constraints (e.g., fatigue) on freight operations. However, the activities of a goods driver can extend beyond the task of driving (including vehicle checks, load checks, administration etc.) and not all freight delivery tasks entail the same driving complexity. These factors may therefore guide the emergence of automated vehicles for the delivery of goods, with the early opportunities likely to appear in highly controlled environments, such as ports, airports and mines, where the complexity of the automation task is reduced and the goods being moved are well organized. Indeed the Port of Rotterdam has operated fully automated vehicles for container movements since 1993 (Bishop 2000) and fully automated mining trucks are now well established (Simonite 2016). In a similar manner, automation of freight vehicles on the public road is likely to emerge in locations where there is control over the environment and where the economic returns are greatest. This has seen a range of companies promising automated highway driving for trucks (e.g., Uber, Waymo, Embark, and TuSimple). Otto (the former name for Uber's automated trucking initiative) demonstrated delivery of a shipment of beer along I-25, Colorado, in partnership with Anheuser-Busch. The articulated truck apparently drove 120 miles from on-ramp to off-ramp with no intervention from the human driver present (Fitzpatrick, 2016). Based on the eventual introduction of such technology, a PWC report estimated automated, long-haul trucking could reduce total transportation costs by nearly 30% through 2040, assuming aggressive adoption of automated trucking (PWC & MI Manufacturing Institute 2018).

In Europe, real-world trials of truck platooning have taken place with vehicles from manufacturers such as Daimler, Volvo, Scania, and DAF participating. For example, convoys of trucks from each manufacturer completed journeys from different parts of Europe, converging on the Dutch port of Maasvlakte. Drivers were present in all trucks but only the lead vehicle was fully driven by a human driver. ElectronicE connections between the lead truck and following trucks managed acceleration and braking to enable closer following distances. Such demonstrations have shown real-world improvements in fuel efficiency of 8% (Chan et al. 2012). In an industry where fuel costs represent an average of 21% of truck operating costs in the United States (Hooper and Murray 2017) and 26% of operating costs in Europe (Meszler et al. 2018), this represents a significant potential improvement in profitability, if platooning can occur on significant portions of journeys and if the technology to deliver platooning is proven as safe and is not prohibitively expensive. Furthermore, to date, trials of platooning have tended to be between vehicles from the same manufacturer. To maximize the opportunity for platooning to take place, it will be necessary to achieve multi-brand platooning where trucks from different manufacturers can platoon interchangeably, such as with the ENSEMBLE project mentioned in the previous chapter.

The introduction of automated vehicles to the freight industry has caused concerns about job losses: the role of human truck drivers will be taken by automation technology (Beede et al. 2017). The International Transport Forum (ITF) has predicted that up to 4.4 million of the 6.4 million professional trucking jobs in the United States and Europe could be eliminated by autonomous technology (ITF 2017). This concern is underlined by the popularity of truck driving as a form of employment; a recent study (Bui 2015) indicated that truck driving was the most common job title in the majority of U.S. states. However, in both the United States (Costello 2017) and Europe (e.g., Todd and Waters 2018), the logistics industry has seen a shortage of drivers. In the short term, it may be that automated vehicles mitigate this human driver scarcity. In the longer term, when automation may play a greater role in the movement of goods by road, the transition away from truck driving as a common form of employment may be effectively managed. This may include roles in managing operations from regional control centers and a range of different tasks associated with the maintenance and management of automated delivery vehicles.

There are also benefits from automation that do not result in the loss of delivery drivers from the workforce. Truck drivers in the United States (FMCSA 2011), European Union (European Commission 2006) and globally (e.g., Australia: National Transport Commission 2006) are strictly regulated in the interests of safety and fair working conditions. If automation can be proven to manage long periods of highway driving safely and efficiently and if the workplace environment for the driver can be made acceptable (toilet facilities, refreshments, connectivity etc.), it may be possible to lengthen the operating window for truck operations leading to increased delivery efficiency. While the AV manages driving for long stretches of the highway, the human driver can engage in other administrative tasks or relax. The driver would need to be able to resume controls when needed through a managed and practiced procedure and with appropriate failsafe systems, should a driver fail to respond for any reason. These changes in the responsibilities of the role of the driver may require a different skillset and additional or different training to maximize productivity.

The safety and economic benefits of driver assistance technologies have driven their adoption in regulation in the European Union with lane departure warning and automatic emergency braking systems made mandatory from 2014 (European Commission 2009). In the United States, there has been significant trialing and development of platooning technology to improve vehicle fuel efficiency (e.g., Peloton, see Simpson 2018). If the implementation of higher levels of vehicle automation can further reduce the incidence of collisions, these benefits can be extended still further with greater vehicle uptime and reduced insurance and repair costs, but also with the employment implications discussed above.

The ability for vehicles to move without human operators means that vehicles can be developed to suit the delivery requirement and transport environment without the need to consider accommodation of a driver. This has led to a proliferation of small, robotic vehicles (e.g., Starship Technologies, Nuro) intended for very low-cost, short-range urban deliveries. Such vehicles may help tackle the impact that the growth of online deliveries has had on city traffic (Visser et al. 2014). The Starship vehicles have undertaken trials of grocery (Karasin 2017) and food (Gerrard 2017) deliveries. If this is proven to work successfully, this could enable a more significant transformation toward the sharing economy, where material ownership of items is less critical if they can be delivered and returned at very low cost and at user convenience. However, there has been some resistance to their deployment (Wong 2017). There could be serious induced demand and VMT/GHG effects, which could also limit acceptance. As with Jevons' paradox (Jevons 1865), an unintended consequence of increased delivery efficiency might be a dramatic increase in the number of deliveries being undertaken. While trials of small numbers of vehicles may be seen as acceptable, regulation may be needed to mitigate the effect of their presence on the experiences of pedestrians, cyclists, and the wider traffic environment when deployed in larger numbers.

Passenger Transport

Many current automated vehicle trials are offering different varieties of passenger transport. These include Waymo (Korosec 2018) and Aptiv/Lyft (Etherington 2018), trialing automated passenger car services; Navya (Christie et al. 2016) and Easymile (Robarts 2015), offering automated bus operations with up to 12 passengers per vehicle; and Aurrigo (Parmenter 2017) and nuTonomy (Ackerman 2016), seeking to deploy small, personal vehicles dedicated to urban environments (discussed in prior chapter, referencing Stocker and Shaheen Forthcoming). Although they are exploring different business models, each is focused on the opportunity for using automated vehicles to move passengers in towns and cities (Stocker and Shaheen 2016; Stocker and Shaheen 2017). These approaches stem from a belief that private cars contribute to urban congestion, and city mobility can be significantly improved by connectivity and automation. While the role of AVs may enhance transportation opportunities in urban environments, it should also be recognized that some European (e.g., Amsterdam, Copenhagen) and U.S. cities (e.g., Atlanta, Chicago) place a significant emphasis on the role of active travel (walking and cycling) for cities. This is captured by the London Mayor's Transport Strategy (Greater London Authority 2018), while a vision for the balance between existing modes, AVs, and active travel is neatly described in the 'Blueprint for Autonomous Urbanism' (NACTO 2017) produced by NACTO. Each document sets out how technology and urban design should be used to support the needs of the city by applying people-centric design.

The focus on urban environments for AVs is logical given the density of customers and need for new forms of mobility in those areas. However, (re-)connecting rural areas may also provide opportunities for CAVSM. Profitability is challenging when confronted with practicalities of operating large buses to enable transport outside of cities. However, connectivity and shared transportation can be used to enable greater demand responsiveness, while automation may be able to reduce operating costs further (see for example, http://innovativemobility.org/wp-content/uploads/Mobility-on-Demand-Operational-Concept-Report-2017.pdf). This may support mobility for older travelers who are more likely to live in rural areas and may have to give up driving, having been car dependent. Similarly, such transportation may help younger residents access educational facilities and broaden the employment horizons for rural residents (Shergold et al. 2016).

Connectivity in the workplace has threatened to revolutionize travel for many years. Nearly 40 years ago, it was speculated that commuting would fall dramatically as connected workers would be able to log-in from home (or wherever) to accomplish their office duties (Toffler and Alvin 1980). However, although remote working is now possible for many office-based employees, demand for mobility has not (yet) diminished as predicted; commuting by road remains a significant component of the working lives of U.S. and EU citizens. However, urban areas commonly tend to exhibit a traveling time-distance radius (or travel time budget) of 45 minutes (Muller 1995). The potential to use CAVSM for commuting could dramatically change lifestyles and working practices and change this time-distance radius. First, by increasing the speed and efficiency of transportation, the boundary of the time-distance radius may be extended outwards away from the center. Second, the comfort and convenience afforded by AVs may enable greater flexibility in the use of time when traveling, for example, enabling work on the move, such that commuters may be more comfortable traveling greater distances (Maia and Meyboom 2018). Also traveling during peak hours may increase if delays are perceived to cause less harm. This may result in induced demand and increases in vehicle miles traveled and emissions if demand is not managed by pricing regimes or capacity is not increased in line with the increased demand. These secondary effects may mitigate the potential societal benefits of AV transportation. A later section of this chapter presents a discussion of congestion impacts.

Shared transportation services are enjoying significant growth, enabled by connectivity and by the market penetration of smartphones, through which such services can be accessed (Shaheen et al. 2016). Other societal trends support this growth. In particular, the tendency for millennials to drive less than older age groups and being more likely to use technology to substitute for travel (*Op. cit.*). A variety of new concepts have emerged including carsharing, ridesourcing/e-hailing, microtransit, and digital ridematching (*Op. cit.*). There are many potential impacts associated with the uptake of such services. For example, in addition to potential reductions in congestion and pollutant emissions, joining a carsharing scheme is estimated to save U.S. households $154–$435 per member per month (Shaheen et al. 2015).

In areas that are poorly served by public transit systems (and where their introduction might be expensive or impractical), CAVSM services may provide vital accessibility, helping local residents and businesses meet their mobility objectives. This includes helping citizens to achieve educational, medical, social, and employment objectives and businesses to gain access to more efficient supply chains and a broader market. This in turn may help the local authorities by supporting citizens into employment and reducing dependence on publicly funded services for transportation and medical care. However, it should be noted that improving connectivity to a region would be likely to cause the value of properties within that region increase. By reducing affordability of properties, there is a risk that low-income residents would be pushed further away from city centers, exacerbating their travel challenges. As society becomes increasingly urbanized, CAVSM services may help the viability of rural communities through improved transportation (Meyer et al. 2017).

Research has also indicated that the use of ridesourcing services has led to reduced use of public transportation and increased congestion in some urban areas (Feigon and Murphy 2016; Rayle et al. 2016; Clewlow and Mishra 2017; Schaller 2017; Gehrke et al. 2018; Hampshire et al. 2017). Because of this, vehicle occupancy rates in shared automated vehicles are important. Both Lyft and Uber offer shared-ride services, known as uberPOOL and Lyft Line, which are cheaper than regular ridesourcing services but can be more expensive than public transit. Sener et al. (2018) found that likely users of automated ridesourcing services are much less likely to use the pooled version (39%) than the single occupancy version (61%). The addition of automation into the road transport sector need not (and should not) mean that all public transit vehicles operate with no onboard employees. For example, in providing bus services for the elderly or disabled, the role of the driver goes beyond vehicle operation. A driver provides social contact, support in accessing the vehicle and information about the trip (SCR 2018). Freed from the responsibilities of driving, an operative on board such a vehicle would have more capacity to perform these ‘added value’ duties, thereby delivering a better overall service to users.

Job Market Impacts

One of the biggest impacts of connectivity on mobility is the growth of ridesourcing services, such as Uber and Lyft. The development of ridesourcing has created new ways in which people can monetize car ownership and driving ability. Flexibility in where, when and how one chooses to offer service through one or more ridesourcing services means that drivers can choose how much of their time they wish to spend working in their service. Without supervision from a full-time employer, ridesourcing activity is only possible through continuous connectivity that is required to manage operations to find customers and to secure payment (along with support for routing, traffic avoidance etc.).

This style of working is an example of the so-called ‘platform’ or ‘gig’ economy, in which workers operate as freelancers, choosing their level of availability for work and where payment is not in the form of a regular salary but is determined by the number of customers and types of job they are able to complete. This style of working offers useful flexibility for drivers and has created convenience for riders but is associated with a distinct lack of social protection for platform workers (Forde et al. 2017). It is a model that is also threatened by the emergence of automated vehicle services. Uber and Lyft are investing heavily in the exploration of such services to ensure they can take advantage of this technology and compete with emerging rival providers of automated vehicle services such as Waymo, Ford, GM and Daimler/Bosch. This significantly changes the style of operations for a ridesourcing service, shifting more toward the maintenance and management of an AV fleet rather than relying on driver/owners to maintain vehicles appropriate for taxi operations. While the deployment of automated vehicle taxi services is likely to occur incrementally; starting in small regions of cities, once proven to be successful (safe, well received, profitable), their growth could be rapid, reducing the size of this gig economy for on-demand drivers. It is important to recognize the transitional state between current ridesourcing services and full SAVs. There may remain a market (and a need) for human-driven vehicles where by choice or by operational requirement (e.g., a VIP whose safety cannot be entrusted to a vehicle that always stops for obstacles or can potentially be hacked) a human operator is preferred.

At the same time, the potential for AVs to reduce employment cannot be ignored. A U.S. study in 2017 identified that 81% of U.S. adults anticipated that many people who drive for a living would lose their jobs (Smith and Anderson 2017). In 2015, there were 15.5 million workers in the United States employed in roles that could be affected by the introduction of automated vehicles, representing one in nine of the available workforce (Beede et al. 2017). In this report, the authors distinguish 'motor vehicle operators' (those for whom driving to transport people or goods is a primary occupation (e.g., truck drivers, bus drivers, taxi drivers) and 'other on-the-job drivers' (those who drive to deliver services or trades (e.g., construction workers, real estate agents, police patrol officers). The authors assert that automation is likely to have a more significant negative impact on members of the former category, who may find it difficult to find alternative work whereas workers in the latter category depend on a range of other skills in the scope of their employment and may therefore adapt more successfully to the introduction of AVs. Since members of the 'motor vehicle operators' were likely to be male (88%), not educated to degree level (92%) and less likely to have a health plan or a pension or to live in a metropolitan area, it can be seen that supporting this group through the transition to the world of automated vehicles will be important. Although the report offers a rather negative view on the impact of AVs on employment prospects, it fails to recognize the potential for jobs to be created by their deployment. Three areas stand out: (1) software (supporting the programming and development of AV platforms); (2) maintenance of automated vehicle fleets (ensuring vehicles are clean and that sensors, actuators, other associated systems are operating within acceptable tolerances for automated operation etc.); and (3) data analysts (managing and analyzing the terabytes of data that automated vehicles will produce).

That said, it is unlikely that those in roles replaced by automated systems will have been adequately trained by current educational systems to achieve the necessary skillsets required to enter any of these new roles. Goos and Manning (2007) recognized technology as causing a polarization of the job market. There is an increase in demand for well-paid, skilled jobs that involve non-routine cognitive skills and an increase in demand for low paid, low skill jobs that involve non-routine manual skills. Frey and Osborne (2013) highlighted that machine learning and mobile robotics are significantly increasing the number and types of task that can be automated, thereby exacerbating this polarization and with the risk of job automation disproportionately affecting low skill/low wage occupations. A sanguine examination of the risk of automation for jobs in OECD countries (Arntz et al. 2016) estimated that 9% of all jobs were potentially automatable, somewhat lower than the estimates of Frey and Osborne. The researchers emphasized that it was often the task-related content of occupations rather than the occupations themselves that would be automated. However, for jobs where employees are paid solely for driving (as per Beede's 'motor vehicle operators'), it must be assumed that automation will obviate the need for those employees. This specific risk for unemployment in relation to driving must be a consideration for transport authorities in the rush to automation.

There are potential employment impacts other than job gains or losses. Ubiquitous connectivity also changes employees' value of time. Many workers engaged in office-based tasks can remain in contact with colleagues and customers provided that they have telephone and data connectivity. In addition, if transport options provide conditions conducive to work (e.g., seating, refreshments, toilet facilities), travelers can gain value from time spent in public transit. Also sufficient privacy is needed if you plan to work while traveling. While this may help workers to achieve a desired work/life balance, it may also affect willingness to travel and acceptance of longer commutes since time spent in journeys can still be useful. Applied to CAVs, this could increase vehicle miles traveled since passengers may accept more frequent and longer road journeys during which they can remain productive. However, the dynamic characteristics of road transport (lateral and longitudinal accelerations) and behaviors associated with computer work (continuously looking at text on screens) may cause some users to feel discomfort associated with carsickness (Diels and Bos 2016) and so assuming that all travel time can be productive is likely to be false.

Driving for work is typically the riskiest activity in which office workers engage (Broughton et al. 2003). As a result, the crash safety ratings (e.g., NHTSA/NCAP, EuroNCAP) of vehicles have become a factor in purchasing decisions for fleet managers. Over time, collision data will establish the relative risk of collision for AVs compared to human-driven vehicles. If AVs are proven to be statistically safer, fleet managers may be obliged to require employees to use automated vehicle services rather than drive for themselves, not just for reasons of productivity but under their duty of care responsibilities.

Congestion Impacts

Road congestion has a significant impact on economies (Goodwin 2004; Hartgen et al. 2009). It is experienced when demand for a road exceeds capacity and results in delay. For passengers, delay can mean the loss of productive time, missed meetings or missed onward travel connections; while for freight, delay might mean financial penalties for the supplier, loss of business or spoiled goods. The impact of CAVSM on congestion is dependent on many factors. The first factor is the type of vehicle used. If all human-driven vehicles were exchanged for automated vehicles, (assuming there were significant differences in the way the vehicles were driven: significantly shorter time headways, smoother interactions at junctions) this would have a limited impact on congestion. However, if shared and pooling of vehicles is enabled by connectivity and automation, significant efficiency benefits may be achieved. It has been shown that one shared, automated vehicle can replace nine conventional vehicles but also generate increased vehicle miles traveled due to empty operations and repositioning (Fagnant et al. 2015; Greenblatt and Shaheen 2015). However, as TNC operations become more mature, some behavioral adaptations are starting to emerge. There are circumstances in which such services may increase congestion (Schaller 2017) and attract travelers away from bus (6% reduction) and light rail (3% reduction) services (Clewlow and Mishra 2017). When automated transport facilities become available, transport authorities will need to be mindful of these adaptations in approving such operations for service. Although it has been calculated that operating a fleet of shared automated taxis to service mobility needs within a city may be achievable at drastically lower cost than by private vehicles (see Bösch et al. 2017 for review), it may be cities will need to apply fees to such operations to help manage congestion and access to mobility.

The growth of online shopping has changed consumer habits. Rather than making infrequent trips to retail zones for multiple products, a shopper can make frequent online purchases, benefitting from rapid, low-cost deliveries of individual (or multiple) items. This has changed the nature of the logistical challenge of delivery fulfilment with the consequence that cities have growing numbers of small goods vehicles making multiple delivery drops. This has an associated impact on traffic and congestion (Visser et al. 2014).

At present, the majority of vehicles used for such goods deliveries are vans with combustion engines. A growth in the use of such vehicles is therefore also a source of congestion and emissions (Russo and Comi 2012). However, with growing emphasis on air quality and with the emergence of new technologies, other options are emerging. Examples include GNewt Cargo, based in London, which exclusively uses electric delivery vehicles for duties in the city; and PedalMe, also in London, which serves passengers and deliveries within a five-mile radius of the city center using a fleet of dedicated cargo e-bikes. Automation brings the potential for new vehicle formats. Examples include Starship Technologies and Dispatch Robotics, which fulfil local deliveries using mobile robots that traverse pedestrian spaces and can carry small packages to a chosen destination. To date, these systems have tended to be used for deliveries of items such as food or laundry. However, their application could perhaps have further reaching implications. If small items can be delivered at very low cost and on very short notice, the need for ownership of items is reduced. For example, a user could hire a specific power tool for a particular job on a given day, this would be delivered by a mobile robot and then the robot would return to collect the tool at the end of the day. There would be no need for the user to own the power tool, which might otherwise lie unused in storage for the rest of the year. If such schemes became commercially viable, they could transform ownership and usage models for a range of different products and services and empower low-income communities to access these products and services in ways that were previously impractical.

However, it should be noted that the deployment of such mobile robots has not been without resistance. In product development, when only a few such systems are being trialed, the presence of the devices in pedestrian areas creates minimal disruption and can be seen as a novelty. There are concerns that in commercial deployment, the presence of large numbers of such vehicles could intrude upon pedestrian spaces. In 2017, San Francisco enacted regulations to control the operation of such vehicles, restricting their use to specific industrial regions and sidewalks that are at least six feet wide and requiring the vehicles to be accompanied by a human operative (Wong 2017).

A further opportunity may be enabled by very low-cost delivery services achieved by CAVs: if a shopper does not need to transport their goods home with them but can rely on delivery of products to a place and at a time of their choosing, they may be freer to choose which transport mode they prefer (see Shaheen et al. 2017). For example, a person buying a bulky or heavy item may not be comfortable cycling home with that item but if low-cost home delivery can be arranged (mediated by CAVs), cycling to and from the store may be seen as acceptable.

Impacts on Land Use Values

While uncertain, CAVSM has the potential to significantly impact land use values. For example, the shift toward the convenience of online shopping and the easy parking in out of town shopping malls presents a challenge to city center retail zones (Jones and Livingstone 2018). Higher rents in premium city center locations combined with falling numbers of shoppers means that it can be difficult for such stores to maintain profitability. However, the emergence of AVs may reverse this decline. Such vehicles would be able to deliver shoppers directly to the city center without worrying about parking. Furthermore, the vehicle would manage the stresses of having to drive in city center traffic while occupants could be shown advertising messages promoting products and services on offer in the city center. If CAVSM were to restore the popularity of city centers as destinations, it could provide the impetus for wider rejuvenation of such districts.

In fact, the emergence of highly automated vehicles challenges the need for parking infrastructure in cities and reduces the need for housing developments to include parking, which have significant economic implications (reviewed in Litman 2016). A significant area of land in urban regions is dedicated to vehicle parking. An analysis of selected areas within Sacramento found that parking covers about 11% of the downtown, 26–39% of the industrial areas studied, 30–57% of commercial areas analyzed and 6–26% of the residential areas examined (Chester et al. 2015). The availability of parking is an influential factor in trip planning and even choice of home location. V2I connectivity is enabling new parking services to emerge that seek to provide drivers with knowledge of available parking spaces near their desired destination and even to enable booking of and payment for parking slots. Choosing to share vehicles reduces the per-traveler parking demand and parking costs can be shared.

The benefits of CAVs are expanded if travel is by shared autonomous vehicles. Zhang and colleagues (2015) used a simulation approach to estimate that the used of shared autonomous vehicles in an urban environment could reduce parking demand by as much as 90%. If such services reduce the need for parking, the value of land may be significantly affected and existing parking lots can be reclaimed for other purposes. The land hosting existing car parks in city centers may represent a hugely valuable asset that can be repurposed for other means. Similarly, city center shops and amenities that do not have access to good parking facilities may become more valuable if users are able to access stores more effectively by using automated vehicles that can drop off consumers close by. However, while it is possible that AVs will reduce the need for parking, it does not of course eradicate the need completely. AVs will need to be stored, cleaned and maintained in secure premises, the location of which will be optimized to support the operation of the vehicles. Further, city authorities are unlikely to welcome the prospect of free-floating, unoccupied vehicles circulating in traffic while they await assignment to their next journey. Consequently, they will need to find suitable waiting areas.

Equity

Key Takeaways

- There are significant potential socioeconomic benefits of CAVs, the distribution of which may change social equity in a positive or negative direction.
- CAVs could enhance equity by improving access to opportunities through increased mobility, particularly for those who have fewer options at present.
- Potential for inequity in safety and air quality impacts must be considered.
- Technology can act as a barrier to new mobility services for those less familiar with its use and/or not able to use electronic financial services.
- Integration of private CAV services with public transportation must be carefully overseen to ensure equitable distribution of transport options.

Why Equity Is an Important Socioeconomic Impact Issue for CAVSM

Social equity for governmental organizations relates to the fair distribution of services across its potential recipients. The subject of equity is an important socioeconomic consideration for CAVSM because it is anticipated that CAVSM technologies may dramatically enhance access to mobility for people and businesses (Lazarus et al. 2018). Access to opportunities (Martens 2012), often mediated by mobility, is a key determinant of prosperity and well-being in society (Eddington 2006). The vehicle designs and technologies used, the markets addressed by CAVSM and the regulations imposed upon such services are all factors that may exert a strong influence over how these mobility enhancements are distributed. For the purposes of this paper and in relation to CAVSM, we consider equity in terms of the distribution of socioeconomic outcomes associated with CAVSM that serve to reduce inequality, deliver a fairer and more just society and that provide more options (in mobility and in life) to those that have fewer at present.

Safety Considerations

As discussed in a previous chapter, safety is a potential benefit of connected and automated vehicles. To date, new luxury vehicles have tended to be the vehicles with the best safety systems. Over time, driven by regulation, by market demand and/or by economies of scale in deployment of such systems, these safety features should be integrated into less expensive mass-market models. This cascading of safety systems from luxury to mass-market vehicles gradually broadens the safety benefit that such technologies can achieve. However, the drivers that present the highest crash risk on the roads (typically younger, typically male; see e.g., Helman et al. 2010) tend not to drive newer vehicles that are equipped with the latest safety technologies. With the development of vehicle automation, some authors (e.g., Fagnant and Kockelman 2018; Greenblatt and Shaheen 2015) have envisioned a new era of carsharing where users do not own vehicles but access appropriate vehicles on an as needed basis. For sound commercial reasons, the operators of such vehicle fleets will be able to make evidence-based judgments over the vehicles they deploy and the safety systems that are present on each vehicle. Similarly, consumers may be able to select their preferred vehicle supplier based on known safety risks. Furthermore, given greater utilization of the vehicles within their fleets (and like hire car companies today), operators are unlikely to hold vehicles for more than two years. As a result, a customer of a shared vehicle fleet is likely to encounter vehicles that are relatively new and fitted with the latest safety systems. If such fleet operations are accessible to younger drivers, this may reduce inequity between younger and older drivers in terms of their access to vehicles that are better at avoiding (or mitigating the impact of) collisions.

The significant and hard won improvements in road safety achieved in Europe and North America since the 1960s are often attributed to the "three Es" (e.g., Pease and Preston 1967): Engineering; Enforcement; and Education (sometimes extended to four by the addition of emergency care). A possibility that may arise when considering the future impact of CAVs on road safety is that practicable short-term gains in these traditional areas may be overlooked in favor of supporting the promises of road safety that high levels of vehicle automation are said to offer (Bajaj 2018). It is therefore important in socioeconomic terms to recognize the danger in overestimating the future benefit of as yet unproven technology against smaller but more accessible gains made by applying current best in class technologies and practices.

Accessibility

A key benefit of AVs is that they may provide transportation for those who are underserved at present and disadvantaged either by not being able to drive because of impairment or age or not being able to access a car (Shaheen et al. 2017a; Shaheen et al. 2017b; Kroger et al. 2018). These include the elderly, the disabled and low-income communities. If low-cost (or subsidized) transportation services can be enabled by CAVSM, it may improve the livelihood of these populations in several dimensions. Firstly, it could provide better access to employment. In low-density cities with sparse public transport services, a private car can be a critical factor in finding (and keeping) paid employment. A recent study by a USC student (Junken 2015) visualized public transit data from 43 U.S. metropolitan regions (Levinson 2013; Owen and Levinson 2014) to compare the accessibility of work by car compared to transit. For Los Angeles, it was found that 92% of jobs required a public transit commute of greater than one hour whereas only 7% of jobs required a car commute of greater than one hour, with other U.S. urban regions having a similar ratio. Similarly, an analysis of the Bay Area in San Francisco illustrated that up to seven times more manufacturing jobs and four times more service jobs were available to residents within a 45-minute car journey than a 45-minute trip using public transit (Golub and Martens 2014). This highlights that car owners have significantly greater access to employment than those who use transit in these metropolitan areas, potentially reinforcing socioeconomic differences between these groups. Grengs (2010) illustrated the importance of automobile ownership in gaining access to jobs for citizens in Detroit, going so far as to recommend improving access to automobiles as an effective means of improving employment outcomes for inner city residents. In a similar way, the ability for individuals to access education services might be significantly increased if cost effective CAVSM services can provide appropriate mobility. This could enable residents to stay in school or to attend higher/further education courses such that their employment prospects are significantly increased.

In terms of healthcare, improved mobility can enable citizens to attend medical appointments more readily. This would mean that they are less likely to miss school/work due to more severe illnesses, and it may be possible to treat chronic conditions with outpatient care rather than inpatient care, greatly reducing the overall cost of treatment. This is particularly important in the context of aging populations in the United States and Europe, for whom access to independent mobility becomes challenging in later life (Giesel et al. 2013). Finally, better mobility enabled by CAVSM could enable discretionary travel to support attendance at social activities such as family functions or hobbies (Parkhurst et al. 2014) and travel itself as a social activity (Musselwhite 2017), thereby supporting greater societal well-being.

Improved mobility could mitigate the negative consequences of food deserts. The term 'food desert' was first used by a resident of a public sector housing scheme in Scotland in the 1990s to capture the experience of living in a deprived neighborhood where food was expensive and relatively unobtainable (Cummins 2014). Since then the term has grown in popularity to describe urban areas where residents do not have access to healthy and affordable diets. Living in such an area may contribute to social and spatial disparities in health outcomes (Beaulac et al. 2009). In a study of Cologne, Germany (Schneider and Gruber 2013), it was found that residential areas with low income and high deprivation levels had higher availability of unhealthy products (e.g., alcohol, tobacco, fast food) than in affluent neighborhoods. By improving mobility in low-income areas, CAVSM services would enable residents to access a larger number of alternatives, thereby addressing the diet and diet-related risks.

In the United States and the European Union, CAVSM services may bring a significant benefit for rural communities, where the economics for public transport operations are challenging for human-driven vehicles but may become viable for SAVs. Such services would be similarly beneficial for non-car users in cities that are more car-oriented (e.g., Los Angeles, Rome), where walking and cycling are difficult and public transport services are sparse. Conversely, in the centers of congested, dense cities with existing high-quality public transport services (e.g., London, New York, Copenhagen), such a service may be counterproductive.

While the use of CAVSM to increase access to services can be seen as positive for the affected communities, there is an associated risk. It is established that when the accessibility of a region is improved, the desirability of that region increases with an associated increase in property values (e.g., Rosiers et al. 2010; Diaz and McLean 1999; Forrest et al. 1996). Those who live within these regions and are unable to stay due to increasing prices may have to move to a lower cost area where the access challenges are worse. This may further marginalize low-income residents, pushing the issues of mobility for low-income neighborhoods further away from city centers and potentially exacerbating the problem. The potential influence of CAVSM on land use and property prices should be overseen in this context.

Inclusion

An important equity issue is the extent to which transport services enable those with additional travel needs, such as the disabled and/or elderly, to satisfy their mobility requirements. With the elderly being more dependent on car use, it is important to note that cessation of driving is predicted by older age, female gender, vision and hearing problems, poor cognitive and physical functioning, low socioeconomic status, and nursing home placement (Anstey et al. 2006; Edwards et al. 2008; Freeman et al. 2006; Gallo et al. 1999). As discussed earlier, being able to travel can make the difference between being able to gain further education, to find/maintain employment, or to attend medical appointments. Connectivity may help in gathering data to understand who has additional travel needs and precisely what those needs are, as well as to know from where they wish to travel and to where they wish to go. On-demand CAVSM services may then be tailored to address these mobility requirements in ways that are not practical today, accommodating differences in physical, mental and sensory ability and technology awareness. An example project, Insight, addressing this issue is developing automated vehicles that are accessible by visually impaired users (http://insight-cav.com/).

On the other hand, data emanating from connectivity may lead to inequitable outcomes. Analysis of these data could enable CAVSM service operators to achieve greater depth in their understanding of which vehicles and which passengers tend to use which routes over the course of hours, days, weeks, months and years. The results of such analyses could enable AV operators to determine effectively which routes their vehicles should use. Operators may choose to price routes differentially, depending on willingness to pay. Opting to take a cheaper route may take passenger or freight road users on longer journeys whereas those willing to pay more could access faster 'premium' routes with better roads and more reliable journey times. A corollary impact of this differential pricing may be an increase in traffic volumes being routed through low-income neighborhoods, with associated congestion and collision risk. Consequently, it will be important for city authorities to understand how such services and pricing models impact mobility across their networks and to have the regulatory power to influence how such services are operated in order to manage equity and inclusion appropriately.

In addition, one of the biggest barriers to use of on-demand CAVSM among populations with additional travel needs is the lack of a smartphone and/or bank card (National Association of Counties 2017). Many new passenger services depend fundamentally on the use of internet connectivity, often through a smartphone, which can exchange important data between the user and the operator. Such data may include personal data about the user, their location and confirmation that they can pay for the mobility service via an electronic payment service. This significantly restricts access to such mobility services to those who have access to the necessary hardware (smartphone) and the right data package, the ability to download/operate mobile applications that can use electronic forms of payment and those that are comfortable using a smartphone. Smartphone users in both Western Europe and the United States represent just less than 70% of the population (Statista 2017 2018). Clearly then, mobility services which depend fundamentally on a smartphone would not be accessible to more than 30% of these populations. In high-income European countries and the United States, around 93% of individuals aged over 15 years have bank accounts; however, in lower-income European countries, this figure falls to around 60% (Demirguc-Kunt et al. 2018). In all cases, it is the younger, less-educated and out of work populations that are over-represented in the unbanked group. An even larger proportion of the population is considered to be underbanked: individuals who may have an account but lack access to or choose not to access mainstream financial services. Consequently, a significant number of potential mobility users could be deprived by inadequate banking facilities, with younger, undereducated and unemployed individuals most at risk. This creates challenging societal inequity through poor access to mobility services. Options to address this problem include the use of prepaid cards, distributing vouchers to trial services to encourage uptake, managing payment for mobility services through housing payments, and providing cash payment options (Serebrin 2016).

The equity of service provision–who gets served and at what cost–is a significant issue in the proliferation of SAVs. These services have the potential to be run at much greater efficiency than is achievable today (Fagnant and Kockelman 2018; Greenblatt and Shaheen 2015). By increasing vehicle use and operating costs, profitability can increase. If profitability becomes the key priority, SAV services may be less likely to serve rural, less dense, and some low-income neighborhoods. To avoid facing the challenge of low-demand, such services tend to start in places likely to support highest usage–those with a sufficient density of people and uses. Further, as discussed previously, it may be that roads authorities apply tariffs to manage the potential increase in VMT/VKT on their networks. This creates an opportunity and a challenge: to manage the equitable provision of mobility across a city. The distribution of tariffs applied by the authority may allow low-income neighborhoods that are poorly served by public transportation to be served by mobility services at lower costs whereas areas with good quality public transportation links and infrastructure that supports active travel may have higher tariffs on new mobility services to limit their use (Shaheen and Cohen 2018).

Public Transit Effects

One characteristic of some forms of shared mobility service is that they can blur the lines between private and public transportation systems. For example, in 2017, the urban navigation and mapping company, CityMapper, introduced a 'SmartRide' service to London, its website describing the service as "a hybrid between a bus and a cab," "a real-time, demand-responsive service," and "complementing the existing transport infrastructure" (see https://citymapper.com/smartride). Users register for a service on a mobile application and can then request a ride by specifying their start and end locations, using the CityMapper journey planning mobile application. The application then informs the user where to go in order to get picked up by a CityMapper vehicle and where they will be dropped off near to their chosen destination. The operated services were developed based on data collected on the movements of individuals across the city and resulted in service routes that could satisfy their predicted unmet demand for mobility at these locations. This approach mirrors similar services such as Chariot (backed by Ford, operating in San Francisco, Austin, and London) and Via (operating in Chicago, New York, and Washington D.C.).

A challenge for these new services is how they will integrate with existing public transportation services and projects are examining this concept (e.g., RAMONA project in Berlin, Germany: http://www.dlr.de/vf/desktopdefault.aspx/tabid-2974/1445_read-50061/ and MERGE project in London, UK: https://mergegreenwich.com/). In Europe and in the United States, these public transportation services are tightly regulated, often with a requirement to serve routes/areas that are typically unprofitable. There is a risk that public authorities could gradually cede greater responsibility for transit services to third parties that would focus on profitability over service to the community, potentially resulting in reinforcement of inequities. However, it would appear that the disruption caused by such private services is limited to high end transportation business rather than for the working class, while the profitability of ridesourcing services such as Uber and Lyft remains challenging (Walker 2018). The development of innovative mobility services, especially when empowered by CAV technology, is likely to create opportunities to support mobility in ways that have previously proven to be impractical; however, it is likely that these will need to be monitored and regulated to ensure that their introduction helps to support mobility across the full spectrum of need.

Air Quality

One of the ways in which city residents can experience inequity is in the quality of the air that they breathe. Dense urban districts with heavier traffic flow are at greater risk of higher concentrations of pollutant emissions including nitrogen oxides and particulates. Low-income and minority populations tend to live closer to major roads (Gunier et al. 2003) while the effects of traffic-related pollutants are known to be greater for low-income individuals (Meng et al. 2008, Espino et al. 2015). The shift toward smaller, lower emission vehicles for goods distribution and passenger transport may be facilitated by CAVSM technologies since the duty cycle for an urban transportation vehicle can be comfortably fulfilled by an electric vehicle. Cities can potentiate this change by adopting regulations that encourage the use of lower emission vehicles. By example, London's Ultra Low Emission Zone (to be launched in April 2019), will only permit vehicles that surpass certain emission standards to enter a central city zone. It should be noted however that addressing the air quality issue as a symptom of inequity is not necessarily addressing the cause of inequity itself.

This section of the paper has identified a number of ways in which CAVSM services might benefit citizens and businesses. However, the ways in which these benefits are distributed will be heavily influenced by the regulatory environment into which they are deployed. As such, regulators can choose to offer minimal intervention that may result in a wider array of innovative services being developed but that does not necessarily serve the best interests of all segments of society and may present higher safety risks. Alternatively, they may be more prescriptive over the introduction of CAVSM services perhaps resulting in constraints on innovation in transport provision but with a more defined vision over how such services should be used to improve safety and mobility for city residents and businesses. Given the potential benefits at stake and the safety concerns associated with transport operations, it is the influence of policymakers in public office in the latter approach that would seem to preferable over the former laissez-faire regulatory approach.

Discussion

Connectivity in the transport network has led to the emergence of services that have had a major impact on mobility. It seems likely that automation of road transport services will cause a similar or perhaps even greater transformation. Given the huge investments being made in the sector, it has frequently been stated that the introduction of AVs is not a question of "if" but "when." However, the potential for socioeconomic change resulting from their introduction, means that questions of "where," "how," and "why" have equal importance. The uncertainty around the answers to these questions means that the associated socioeconomic impacts of connected and automated vehicles is difficult to estimate. In this paper, we have attempted to characterize some of the risks and opportunities that are emerging around this potential impact.

Data Privacy and Access

CAVSM data enable individuals to be located in a specific space and time. These data contribute to opportunities for greater societal benefits (i.e., increased accessibility and mobility, harmonized traffic flows, innovative mobility services). At the same time, the more detailed the spatial location, temporal position, or individual information included in the data, the more privacy sensitive the data are and the greater the privacy risk. Privacy regulation is much more protective in the European Union than in the United States, particularly with the GDPR that is now in effect. Issues connected to open data, data sharing, and data ownership that are all highly associated with CAVSM have the potential to increase privacy risk, which is the likelihood of a privacy problem occurring and the potential magnitude of harm arising from the privacy problem. Linking the degree to which data access is controlled (i.e., greatest ease of use of data to greatest privacy protection) is important for mitigating negative societal impacts from misuse or mistreatment of personal information.

Safety and Security

Safety often refers to road traffic safety. When people drive a vehicle, they not only increase their own risk of a crash but also increase crash risks for other motorists, as well as pedestrians and bicyclists. This consequence reflects the social cost of driving, which includes spillover effects on the rest of society such as congestion costs, net output losses, and hospital costs. CAVSM has the opportunity to mitigate as well as exacerbate safety risks. Because more than 90% of traffic crashes are attributed to human error, CAV may greatly reduce these types of error. But CAV may introduce new types of errors such as those resulting from premature release of hardware or software, weather-related technology failures, and cybersecurity attacks. Testing on public roads (supported by legislation, funding, and government oversight) is critical for the development of safe operation of CAV. Many such demonstration and large-scale tests are happening in the European Union and in the United States.

Economics and Workforce Issues

Prosperity is enabled by access to opportunities; transportation enables greater access to opportunities. New mobility services that use connectivity (current) and automation (future) are increasing transportation options for passengers and freight. Consequently, there is the opportunity for such services to increase prosperity across European and U.S. societies. However, as such services emerge, it will be important to be mindful of other changes that they may bring. In particular, automation of the driving task may remove a significant source of employment for otherwise low-skilled workers. The predicted benefits of safety and efficiency that accrue from automation mean that this should not be used to delay its introduction. However, consideration as to how this transition is to be managed will be important. Similarly, changes to mobility may bring about changes in working styles. Time freed up from driving may be used productively for some parts of a journey. This may have a significant impact on land use values and urban planning. Again, it will be for regulatory authorities to monitor these developments and ensure that such secondary effects of transportation are managed to benefit society.

Equity

Issues around the impact of CVs and AVs on society lie at the heart of how these technologies could bring about changes to social equity. It is early in the implementation of these technologies to state conclusively the full extent of the positive benefit on road safety they may have; however, that such benefits may be distributed more quickly and more equitably as we transition to shared, automated vehicles is a distinct possibility. Similarly, there is the potential to increase mobility options for those who at present have fewer, such as the elderly, the disabled, and poorer communities. However, the interests of these communities will need to be represented in the regulatory regimes that emerge to manage the deployment of connected and automated services to ensure that these benefits are achieved.

The emergence of AVs represents one implementation of a wider issue around the deployment of data-rich, artificially intelligent systems. However, the use of this technology for road transport has important fundamental differences from AI applications that are restricted to digital environments. First, an error in AI that affects the performance of an online service or a smartphone app can be frustrating. An error in AI that affects the performance of an automated vehicle could result in the injury or death of vehicle occupants and/or third parties. Fatalities involving vehicles capable of some level of automated driving have already generated global coverage and reams of commentary, even before official investigators have been able to establish objectively the causes of the crashes. Further such fatalities will occur. To build public trust in connected and automated vehicles, the transportation community must be very clear about the safeguards associated with their testing that are in place to protect the public, why the development of automation is being permitted in public environments and the ethical basis of the decision to proceed with AV development. Well considered, evidence-led socioeconomic arguments may be significant in building the most persuasive case. Second, AVs are being deployed into an environment that is already highly regulated, where the ownership and operation of the underpinning infrastructure is clear and where vehicles will encounter an infinite variety of connected/unconnected and automated/non-automated road users. The strategy adopted by some technology companies to 'land and expand' can empower users with remarkable new services but can also harm existing residents and businesses in unpredictable ways. National, regional and local regulators and infrastructure operators can all exert influence over how our roads are used in relation to all of the major themes explored within this paper. It is vital therefore that those in positions of authority engage with new technologies, understand how they might impact upon society and deliver a regulatory environment that maximizes the positive outcomes that may be achieved by the use of CVs and AVs. Socioeconomic considerations will be crucial in determining an optimal regulatory response to these technologies.

Connectivity and automation are providing the platform for some radical changes in transportation and mobility in the United States, in Europe and globally. The rush to bring technologies to market, the uncertainties around the impacts of potential deployments, and the challenges in effectively operating existing transportation systems mean that it can be challenging for transport regulators to determine the correct response. In these circumstances, a proposed approach would be for regulators not to decide prescriptively what forms of transportation should be used on their networks but to work collaboratively with the industrial and research sectors and engage with their communities to set out ambitious goals for mobility that account for socioeconomic issues, including data, safety, security, economics, employment, and equity considerations. Developers of CV and AV technologies would then be incentivized to develop services that match these ambitions. In addition to any direct engagement, the wider public would have a democratic influence over how these transportation priorities are determined. The appropriate management of interests across the public and private sectors will be vital in attaining the potential benefits (and risks) of connectivity and automation in our transportation system.

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APPENDIX B

Briefing Papers on Exploratory Topics

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Susan Shaheen, *University of California, Berkeley, USA*
Barbara Lenz, *German Aerospace Center, Berlin, Germany*
Barry Einsig, *Cisco Systems, Inc. (currently at CAVita, Washington, D.C.)*
Alex Karner, *University of Texas, Austin, USA*
Marcin Stepniak, *Polish Academy of Sciences, Warsaw, Poland*
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Overview

Alexandra Millonig and Susan Shaheen

Introduction

This briefing paper overview sets the stage for our breakout group discussions as part of the EU-U.S. Symposium on the Socioeconomic Impacts of Automated and Connected Vehicles (CAVs). In this overview, we describe two sample scenarios that could greatly impact four key subtopics related to the socioeconomic impacts of CAVs:

- Travel behavior,
- Freight,
- Land use, and
- Policy/governance (stakeholder response).

Please note that the travel behavior and land-use breakouts use these same scenarios. Both the freight and policy/governance[1] (stakeholder response) subtopics customize their scenarios in varying degrees but still offer two opposing views based on the same scenario vectors of market penetration levels and public policy contexts, as described below.

In the scenarios, we focus on different CAV market penetration levels (strong and weak forces) and public policy contexts (high and low government regulation). We present two contrasting scenarios to launch our discussions for each subtopic and each of the cross-cutting issues:

- Economics and the workforce,
- Equity,
- Data access and privacy, and
- Safety and security.

The first scenario is primarily market driven with little regulation. The second reflects a more highly regulated world in which the public is much less accepting of automation. Not surprisingly, it is also much less market driven.

Scenarios and Context

As noted, we have created two scenarios to assist us in assessing the impacts of CAVs in the future. It is important to note that our breakout discussions are not restricted to these worlds, which reflect high and full

[1]The freight subtopic defines the two opposing scenarios as: (1) "Automated Vehicles Taking Over Transport Business" and (2) "Automated Roadway Freight Restrained by Policy." The policy/governance (stakeholder response) subtopic defines its two opposing scenarios as: (1) "CAVs on the Rise" and (2) "CAVs Tamed by Policy."

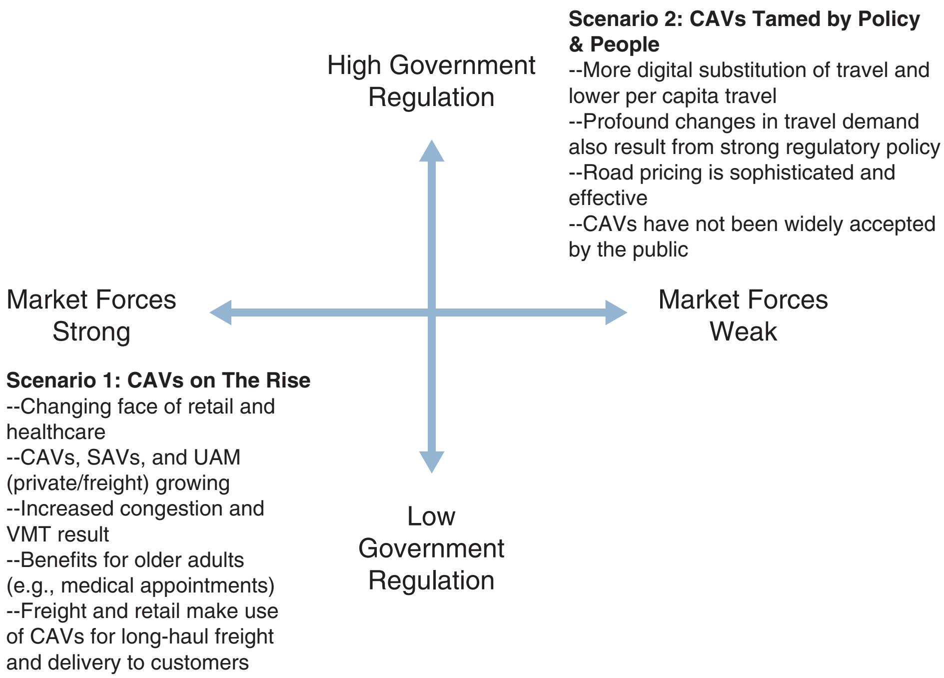

FIGURE 1 Travel behavior impacts of automated and connected vehicles (Millonig and Shaheen, see briefing paper on Exploratory Topic 3).

levels of automation (Levels 4 and 5).[2] These scenarios are intended to accelerate our discussions in each of the breakout discussions and to aid us in developing high priority research problem statements in the four subtopic areas: (1) travel behavior, (2) freight, (3) land use, and (4) policy/governance, which also address the four cross-cutting issues: (1) economics and workforce issues, (2) equity, (3) data access, and (4) safety and security.

We define our two framing and contrasting scenarios (travel behavior and land-use breakouts) as: (1) "CAVs on the Rise" and (2) "CAVs Tamed by Policy and People." Please see Figure 1, which positions these scenarios in opposite quadrants based upon two axes: (1) high/low government regulation and (2) market forces strong/weak. While these scenarios focus on the highest levels of automation, we should also think about the transition to highly automated vehicles as part of our discussions and in our research problem statement formulation.

Scenario 1: CAVs on the Rise

CAV services are offered by different competing private companies or private people using their vehicles as an additional source of income. CAVs come in different sizes and models for different purposes (e.g., business vehicles for working, entertainment vehicles) and can be booked at lower rates for regular and/or shared trips or specifically hailed causing higher costs, as fleet management must reschedule trips to serve new requests. Sharing is common for saving costs, but some groups refrain from using shared services with strangers (especially at night), although vehicles are equipped with a surveillance system and users are identifiable—there is even a rating system for co-riders.

Almost everyone is using CAVs also for short trips, even if the traffic is congested or slow, as it is very convenient and time can be spent for different purposes. As the demand for other transport modes has been dramatically decreasing, public transport has been reduced and few people use bikes or walk. However, several areas in the city have been reserved for pedestrians and microvehicles (like hoverboards and electro scooters) for recreational and retail purposes, although most people rarely go shopping as most purchases are made online.

[2] The Society of Automotive Engineers (SAE) has defined five levels of vehicle automation, with Level 1 signifying vehicles that automate only one primary control function (e.g., self-parking or adaptive cruise control) and Level 5 referring to vehicles capable of driving in all environments without human control (U.S. Department of Transportation 2016]. The majority of AV pilots thus far are targeting Level 4 automation, where a human operator does not need to control the vehicle as long as it is operating in a suitable operational design domain (ODD) given its capabilities. (Stocker and Shaheen 2018, Forthcoming).

Outside the cities, there is practically no other transport mode used besides CAVs.

Scenario 2: CAVs Tamed by Policy and People

Due to international commitments to dramatically improve climate conditions and reduce the consumption of land and resources, governments have implemented effective measures on transportation to significantly decrease traffic volumes (e.g., road pricing). This development is supported by considerable changes in the production sector (e.g., emerging technologies like automation and 3D-printing accelerate local productions and teleworking becomes common). Further, a paradigm shift occurs towards more sustainable, local lifestyles. This results in a landscape of smaller communities where people spend most of their time, but they are highly connected to other parts of the country through telecommunication.

If possible, people follow their daily routines in the close vicinity, working in local community centers offering teleworking spaces and covering the majority of the distances by walking or using shared bikes or micro-vehicles (e.g., hoverboards and electro scooters). Smaller CAVs are only rarely used for passenger transport (e.g., by people with disabilities or to reach larger hubs for mass transportation) and are strongly regulated as the use is only granted to specific groups, but are common for transporting goods, as people prefer to get their purchases delivered than carry them. For longer distances, automated public mass transport is used, but people usually avoid having to travel longer distances on a regular basis. Only a small elite employ private AVs, mainly to display their status (as these are very expensive) and distinguish themselves from other citizens.

Exploratory Topic 1

Synthesis of the Socioeconomic Effects of Connected and Automated Vehicles and Shared Mobility-Freight

Barbara Lenz and Barry Einsig

Introduction

This briefing paper focuses on freight—both long-haul goods transport and urban or regional delivery. The fundamentally different situation for long-haul and urban delivery represents a particularly complex challenge when designing a "world of road automation." While keeping this challenge in mind we oriented our thoughts along the public policy context (high and low government regulation) on the one hand, and the opportunities as perceived by actors on the markets on the other (fast and decelerated implementation). We defined two scenarios to launch our discussions for each of the cross-cutting issues: economics and the workforce, equity, data access and privacy, and safety and security.

Scenarios and Context

The purpose of the scenarios is to assist us in assessing the impacts of vehicle automation in the future. We defined our scenarios using a contrasting approach: (1) automated vehicles taking over transport business and (2) automated road freight restrained by policy. Figure 2 positions these scenarios in opposite quadrants based upon two axes: high/low government regulation and strong/weak. We provide a brief discussion of each scenario and outline research questions based on the four cross-cutting issues related to freight impacts.

Scenario 1: Automated Vehicles Taking Over Transport Business

Automated trucks have become available since the early 2020s, and were quickly adopted by logistics providers, because they dramatically reduced the need to hire driving staff. The implementation produced need for additional infrastructure and maintenance of existing infrastructure; motorways were reconfigured by allocating one track for automated trucks exclusively. National and state funding was provided to build new infrastructures to ease "mixed use" of motorways by fully automated and non-automated vehicles. Investments went in particular in infrastructures that allowed other motorway users to enter and exit the motorways safely. Meanwhile this problem has been solved by software-based solutions as all motor vehicles are automated.

As automation provides high flexibility for transport times and modalities, most logistics providers are now relying on an automated truck fleet either as owners or charterers. Additionally they use all kinds of automated delivery vehicles (including drones). The ongoing implementation of automation in production and commerce has massively pushed road freight automation to create fully automated supply chains.

Road freight automation is not well accepted by society as vehicle automation has resulted in freight transport shifting predominantly to roads. Rail freight was no longer competitive, so that rail lines were transformed into roads for automated long-haul by truck. While freight operations became less costly, they increased the environmental load coming from goods transport.

In the following, we explore possible impacts resulting from automation of freight across the four dimensions (1) economics and the workforce, (2) equity, (3) data access and privacy, and (4) safety and security. For each area, we pose key questions related to associated impacts of the first scenario.

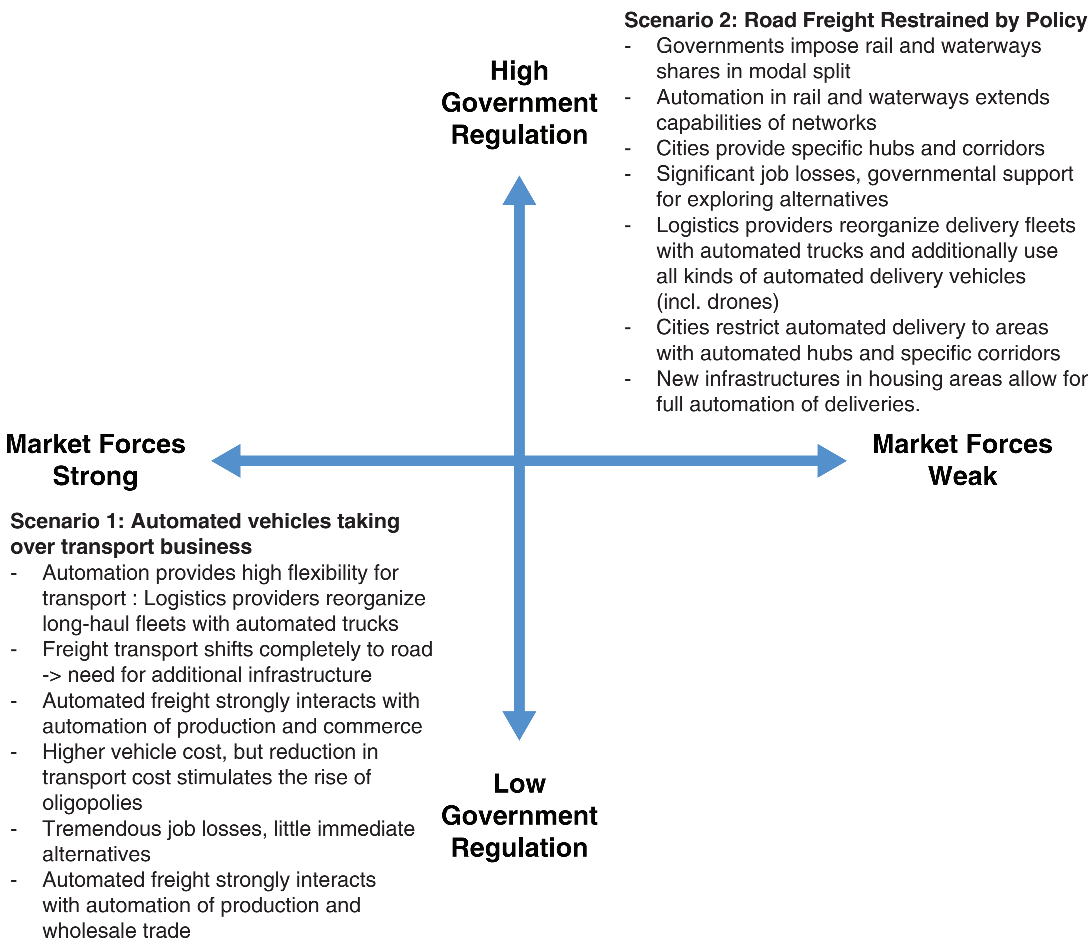

FIGURE 2 Impacts of automated and connected vehicles on freight.

Economics and Workforce

In the freight sector, automation may require considerable investment from the state. For logistics service providers, it is connected with higher vehicle cost. Higher vehicle cost and reintegration of supply chains will impact small and independent trucking and distribution companies who are no longer competitive, and the reduction in transport cost will stimulate the rise of oligopolies. Will the state be able and willing to invest in new infrastructures? Will society accept that the state pays for investments from which only a small group of companies will benefit? Or will new business models come up to provide automation-ready infrastructure requiring motorway tolls?

At the same time road freight automation will cause tremendous job losses among drivers. What could be alternatives to these jobs in the short and in the medium run, but also to job losses that will result from automation along the entire supply chain? What about alternatives for jobs that are currently held by people with lower levels of education and training? Which are the jobs required by an automated freight system? Will the education system be able to provide the required education and training?

And what about jobs and professions related to roles such as planners, traffic operations, parking authorities? Will Artificial Intelligence and Machine Learning from vehicles communicating all the time eliminate these roles currently held by humans? Will the lower cost of transportation cause manufacturers to move further away from populated areas, what will the impact be?

Equity

New road freight corridors will arise and existing ones will carry more shipments resulting in increasing volumes of noise and air pollution. Off-peak delivery into urban areas could disrupt the quality of life, either night life or sleep. Which are the options to avoid a negative environmental burden for those living close to road infrastructures or areas of frequent deliveries? As automation of freight and deliveries might require specific infrastructures for those who want or need home delivery, there will be residential areas where delivery is not or no longer possible. Does this mean that delivery deserts will add to already existing retail and food deserts?

Data Access and Privacy

Smaller firms might lose access to supply-chain data thus no longer being able to collaborate with other companies in the chain. Since the value of the digital information is more valuable to the manufacturer or larger retailer the cost for the implementation may be forced on the smaller trucking company or distribution facility while the economic gains and customer intimacy go to the large manufacturing or retailer without any cost recovery available to the smaller players in the ecosystem. Access to data will probably be part of the freight business. Will small producers, dealers and logistics providers still have the opportunity to be part of the business? Or will large e-commerce platforms become the control center of the entire chain thus applying full domination on production, commerce and consumption? Can blockchain help secure the route of trust in the supply chain and allow all the stakeholders to participate equitably? Will this force consolidation of the supply chain? Could this ultimately drive up transport cost for freight due to the limited options available? May this eliminate particular elements of the market (e.g., wholesale)?

Safety and Security

If automation takes over too soon, it may cause safety issues and lead to resistance against freight automation. How can it be ascertained that software that is used for freight automation provides safe operations for both the driving and the loading and unloading? How can current regulations (e.g., for control of load by police during transport) be "translated" to the case of automation? For instance, is it possible for the police to stop a truck to control the load during its cruise on the motorway? Will we be able to monitor and control smuggling and illegal imports and exports with no humans in the supply chain? Who has access and who can get access to the data that go with freight during transport? How can control about the security of goods be achieved?

Scenario 2: Automated Road Freight Restrained by Policy

Acknowledging that automation of road freight will considerably lower the cost for road freight, thus leading to a complete shift of freight transport to road, governments started early to control and modulate the process. To keep or extend the modal split towards environment-friendlier modes like rail and waterways capabilities of their networks were extended, automation on rail and waterways was heavily subsidized, and larger cities and agglomerations provided specific intermodal hubs and corridors that included facilities for automated operation. Shippers have to follow specific rules to keep an environment-friendly modal split.

States and cities have severe regulation for freight automation to make it a sustainable mode of transport i.e., environment-friendly, safe and efficient. As automated logistics are operating with the highest respect possible towards other road users, including pedestrians and cyclists, children and seniors, it is broadly accepted also in cities and city centers. By creating connectivity systems cities can allow check-in and check-out of delivery vehicles and schedule drop-off times and locations reducing double parking and congestion in the city center. This has helped to further extend home deliveries across cities and regions. New business models have emerged for dual use of automated vehicles: commuters during peak commute times and freight delivery during off-peak times.

Another important factor to generate acceptance within the population for the automation of freight was the better use of resources such as alternative power by automated vehicles, and the obligation to run automated vehicles zero emission either electrically, CNG, or Fuel Cell thus contributing to cleaner air and less CO_2.

In the following, we explore—similar to the exercise for Scenario 1—possible impacts resulting from automation of freight across the four dimensions (1) economics and the workforce, (2) equity, (3) data access and privacy, and (4) safety and security. For each area, we pose key questions related to associated impacts of the second scenario.

Economics and Workforce

Full automation will need regulation to give enough time to make an impact that labor can be reskilled to better quality of life positions. How much will actors in the field of automation—firms, states, cities and citizens—accept any deceleration of automation and its opportunities for new businesses, but also for a new transport system? Which are short and medium term alternatives for those who are already working in the sector? What needs should be formulated towards education and training?

What will be the effect of automation on regional circular economy wherever it exists? Could the dependency on automation empower local restraint of trade and force urban areas' preference for locally made, grown, or developed products and delivery system?

Equity

The reduction of transport cost for manufactured goods by automated freight can increase the buying power of all including poor and middle class. What would this mean for household consumption as well as the production and trade of consumer products? Can automation be made a driver of overall economic development including all segments of the population?

Equity issues could arise if all of the preference is shown for delivery vehicles over other vehicle types or part of the urban environment that is impoverished or outside the local norms or social and political views. Will strong government regulations and significant value creation in the private sector create issues with corruption in the way access is granted by governments to private sector? Can we reimagine a localized logistics and supply chain so as to bring smaller more local focused distribution and help eliminate food and services deserts? Can we use this to free up land in the urban areas that can lead to better utilization for equitable housing, healthcare, or education? How can regulation ensure that private issues are estimated equivalent to business issues? Can we create an equitable system for curb access for freight delivery, with other shared mobility services?

Data Access and Privacy

Governments of all sizes from cities, regional states, provinces, and federal agencies understand the need to be able to exchange data between the many actors in the supply chain and still be compliant with General Data Protection Regulation (GDPR) or other privacy provisions as well as proprietary data from the private sector, and so they create a data broker and exchange to enable the connected and automated vehicles. Much of the data that the private sector has, regarding product mix, shipping times, and even end customers, is very proprietary financial information to the manufacturer or retailer. Whose data should be included in this broker/exchange? Who should operate this system and why? Can the government collect enough of its own valuable data to share and make it an equitable exchange that the private sector will collaborate? How can we secure this data? How will it be exchanged? Will real-time safety and mobility data be enough for the private sector to see the clear advantage? Can enabling these systems create a competitive advantage for regional governments and cities that will differentiate them in the areas of throughput, freight, and velocity from ports, rail, and trucking to retail or individual consumers? Can we build an exchange/brokerage that is beneficial enough for the private companies to want to participate while secure enough to protect the critical supply-chain data of the private companies so that their information cannot get out and have a negative impact on their financial performance (i.e., stock share price or leak out to a competitor to give an advantage to them by exposing shipping dates, quantities, end customers or other key financial metrics)?

Safety and Security

Automated freight vehicles would have to obey laws and enable digital inspections allowing regulators and public safety officials to focus on more positive impacting behaviors. Which actors and aspects should be considered then? Which kind of inspections will still be needed given the fact that the entire supply chain is "digitized," including information about origin and destination of parts and products? Will the public trust these systems for mixed traffic?

Automation of urban delivery systems could create a safer environment. Shift to automated freight and platooning might reduce congestion and fatalities on major intercity relations. How does the operation of vehicles and infrastructures need to be designed to meet this goal? How must—for the "urban case"—delivery vehicles be designed so that pedestrians, the disabled, and other "vulnerable road users" are accounted for?

Exploratory Topic 2
Places Where People Live, Work, and Play

Alex Karner and Marcin Stepniak

Introduction

This paper addresses potential land-use changes that are likely to arise under two very different transportation automation futures. Land use generally refers to the type of structure or allowed activities located in a particular geographic area and their intensity (e.g., residential density, employment density, square feet of retail space).

We concentrate on the possible evolution of the places where people live (residential locations), work (employment zones), and play (recreation and entertainment locations). Historically, changes in transportation technology have preceded substantial changes in the urban form. Faster modes have facilitated the coverage of ever further distances within fixed travel time budgets, extending the scale of human settlement from city to region to megaregion.

Following the common structure of all briefing papers for the symposium, we discuss possible socioeconomic impacts using two contrasting scenarios of the deployment of automation related to the four cross-cutting themes. We propose that in Scenario 1, the widespread implementation of CAVs will drive travel costs to near-zero, reducing the importance of specific residential or workplace locations. On the other hand, the reduction of vehicle use envisioned in Scenario 2 will increase the importance of place. In Scenario 1, access to CAVs is a key factor, whereas in Scenario 2, access to places is of primary importance.

Scenario 1: CAVs on the Rise

The first scenario assumes spectacular, unregulated development of CAVs driven by strong market forces. It leads to the development of a rich portfolio of CAVs of many sizes, with multiple available models serving many purposes. The widespread public acceptance of CAVs means that they are widely used and completely replace traditional vehicles in short order. This transport revolution is likely to deeply transform land use in urban, suburban, and rural areas.

The complete domination of CAVs as the main transport mode means that they will be used even for short trips where previously non-motorized modes may have been attractive. Increased travel comfort, safety, and the ability to use travel time productively will engender a significant increase in trip lengths as the effective cost of travel tends towards zero. The confluence of these factors means that the footprints of regions are likely to expand, increasing demand for land on the periphery of regions for residential purposes. At the same time, city centers are likely to be substantially affected by reduced parking demand, enabling a higher density of economic activities. The space saved from parking in central business districts is likely to be transformed into other uses. However, even shared CAVs require areas for charging, cleaning, maintenance, and parking during low demand periods (e.g., off-peak and overnight). This means that questions remain about the future location and scale of parking in urban areas. Moreover, CAVs are likely to increase demand for curbside drop-off and pickup areas which might partly counterbalance reductions in parking requirements.

Economics and Workforce

The widespread uptake of CAVs envisioned under Scenario 1 will deeply affect the location choices of businesses. Specifically, an increased concentration of economic activity in city centers might be observed, thanks to repurposing land previously used for parking. Rather than needing to park close to a destination, CAVs could easily travel to find parking further away or in centralized locations relatively far from downtown. In the absence of major increases in roadway capacity, the result of this shift is likely to be crippling congestion as more people demand travel to downtown destinations and as CAVs make more empty trips. Although the cost of travel will be reduced, travel time budgets are likely to have a practical limit. As congestion increases, public transit operating on dedicated rights of way becomes a more viable alternative. These possible outcomes raise multiple questions related to the evolution of the future city. Under Scenario 1, cities might evolve in more or less transit- and non-motorized-friendly directions. How will public transit availability play into firms' location choices under Scenario 1?

On the other hand, the reallocation and concentration of retail and service centers may occur. The expected increase in the comfort of travel will favor longer trips to "service hubs," which offer more complex services rather than shorter trips to several small services with more limited offerings. As a result, small- and medium-sized retail and service centers might disappear. Because working while traveling will become the norm, a further dissolution between personal and work time will be observed. Would these changes provoke the development of more polycentric cities (e.g., due to increasingly congested city centers) or, on the contrary, boost a monocentric urban structure?

Equity

Widespread CAV adoption and implementation has a great potential to influence social, economic and spatial equity. On the one hand, CAVs should enhance accessibility for people without access to cars and those who are unable or unwilling to drive (e.g., the young, older adults or people with disabilities, etc.) as they will be able to use CAVs (shared or owned). On the other hand, this enhanced mobility will still have associated costs and will likely require access to mobile technology, raising questions about the digital divide. If public transit services are scaled back and newly available CAV services are higher priced, vulnerable social groups could be placed at a disadvantage. Issues related to shared versus private ownership of CAVs must also be addressed. Thus, ensuring an adequate level of access to CAVs will be crucially important from an equity perspective in Scenario 1.

Further, the widespread adoption of CAVs will have an impact not only on business location choices, but also on residential location choices. One of the possible scenarios leads towards demographically homogeneous residential areas, as particular social groups can more easily concentrate separately from others as they accept longer (but comfortable) travel (to jobs, services or recreation areas). Finally, full dependency on CAVs might also limit access to recreation and entertainment areas for vulnerable groups. They might be affected by limited access to CAVs (due to limited public transport options) or they may face discrimination due to a hard-wired inability to reach desired destinations (e.g., lack of a "permission to drive" CAVs to particular destinations or through particular areas). To what extent are these scenarios possible? Which social groups might be (negatively) affected by the deployment of these scenarios? What policies can be designed to avoid discrimination and segregation of vulnerable groups?

Safety and Security

A full deployment of CAVs will significantly increase safety due to theoretically full protection against human-error-based traffic accidents. Nevertheless, the increase in traffic safety might not be spread evenly among all areas. Places with low CAV access, where walking and bicycling might prevail, could be at greater risk than others for injury or death. Are these differences fair?

Further, the induced travel demand resulting from CAV implementation might significantly limit the walkability of residential and office areas. Moreover, some transport users might prefer to avoid shared modes when traveling from particular locations (or time periods). Thus the "security of a place" (e.g., residential or employment areas) might be related to the modes connecting particular zones. Will travel security (or personal security while traveling) become a factor that stratifies future space and societies?

Data Access and Privacy

The massive implementation of CAVs would facilitate the integration of personally identifiable information with information about residential, workplace, and transportation-related data (e.g., departure times, modes used, traveling companions). Based on this information, the precise characteristics of any individual could be known in principle, including historical activity locations and real-time whereabouts. This data situation presents a great risk as it might provoke discriminatory policies from the state (e.g., in case of individuals/behaviors not supported by a current government), as well as the private sector (e.g., in case of more/less prospective clients). As a result, selected residential areas might be excluded from CAV services and their inhabitants may face serious limitations in their mobility. However, it might also provide an opportunity to provide specialized transport services directly to the areas where and when they are needed most. Again, the key policy question is what are the regulatory and policy frameworks needed to ensure that new opportunities are seized, while avoiding the risks associated with potential discriminatory policies?

Another potential data access and privacy impact relates to land values. The detailed knowledge of who is attracted to a given area (and when) is a powerful tool for both land management and land speculation. Thus, key questions are which CAV data might be used for land-use management, who should have access to them, and how should they be protected?

Scenario 2: CAVs Tamed by Policy and People

Scenario 2 assumes that overall traffic volumes would be reduced because of a renewed effort to mitigate environmental impacts and create dense communities where most needs can be met nearby using non-motorized modes or public transit. Rather than individual CAVs, smaller, slower, and shared multimodal AVs would become the norm (e.g., smaller CAVs, electric scooters). In general, CAVs would be used for goods movement rather than passenger travel. The latter would be limited to connections between main hubs and would have limited applicability to commuting trips.

This scenario would entail a major change in prevailing land-use regimes in the United States where an ethos of "local control" currently dominates. It envisions substantial government intervention in land-use decisions. Transit oriented development and the domination of "small communities" would change the character of places across the land-use spectrum. Thus, the overall density of residential areas would increase, together with their supply of basic services, while teleworking supplemented by local employment centers would dominate the future economy. But without additional intervention to curtail prevailing patterns of segregation, Scenario 2 would also entail substantial equity issues, as discussed further below.

Economics and Workforce

The telework-dominated future envisioned under Scenario 2 raises multiple questions related to economics and the workforce. For most workers, commute times and distances will be dramatically reduced. Additionally, the reduced emphasis on vehicle travel will likely result in improved levels of well-being and health across the population as non-motorized modes increase in popularity and utility.

Because not all jobs are well-suited to telecommuting, there will also be some negative economic and workforce effects under Scenario 2. The societal acceptance of telework as a viable option is likely to vary substantially across and within economic sectors. Substantial low-wage work is concentrated in the service and manual labor sectors. Jobs like landscaping, construction, food preparation, and others will still need to occur in specific locations. How would the reduction of travel supply affect economic sectors that require employment to occur in specific locations? How would commuting trips for workers in these sectors be organized?

Equity

It is unlikely that the relocalization envisioned under Scenario 2 will result in the reversal or erasure of racial- and income-based segregation or employment discrimination that prevailed throughout the 20th century in locations around the world. This means that without explicit policies aimed at integration and inclusion, segregation is likely to continue. Specifically, some areas will be relatively prosperous, with high shares of telecommuters, strong concentrations of local services, and increasingly livable environments. Less prosperous areas will be populated by those unable to telecommute who will likely need to commute into the more prosperous areas for work. Any limitation on transport options or vehicles raises the possibility of discrimination against people with disabilities.

What public policies will most effectively combat these residential and employment location patterns? Under what conditions will the public sector be willing to intervene to ensure progress towards integration? The key equity-related question that runs through each of the cross-cutting themes for Scenario 2 is that non-CAV policies will be required to ensure that the socioeconomic benefits of automation are not felt by a select few but are more broadly shared across the economy.

Safety and Security

The research on neighborhood effects demonstrates the profound impacts of an individual's residential setting on public health, well-being, and related outcomes. In high-opportunity areas, schools are high quality, services are located nearby, crime rates are low, and strong social ties prevail. Those located in Scenario 2's newly compact and convenient areas, generated through increased regulation and public skepticism will likely enjoy improved traffic safety as the "safety in numbers" effect would increasingly dominate pedestrian and cyclist safety outcomes. What about traffic safety in areas populated by non-telecommuting workers (with the continued dominance of vehicle travel)? Should we expect spatial disparities in traffic safety outcomes between particular locations? What kind of policy should be designed to limit the potential negative outcomes of these differences?

The land-use patterns that would prevail under Scenario 2 also present issues from a disaster preparedness perspective. If CAVs are in short supply, large-scale evacuations would become difficult. Of course, in a strong land-use-regulatory environment it's likely that governments would have the power to ensure that development only emerged in locations in which evacuations would be feasible. Which areas would need this kind of treatment or consideration and what kind of actions should government undertake?

Data Access and Privacy

In Scenario 2, limited CAV use would result in the collection of much less personal and location data than in Scenario 1. Nevertheless, a data-related threat to privacy will still exist. Limited options for long- and medium-distance trips will lead to data collection on the positions of particular individuals, even though they would not be as precise and complex as in Scenario 1. What kinds of threats are related to the collection of data through places? To what extent will they differ from those data collected via CAV tracking?

The strong land-use regulations inherent in Scenario 2 also likely entail significant government intervention in the private housing market. One result could be the centralization of personally identifiable information in large databases held by a single agency. These data would potentially be vulnerable to compromise. Given the strong environmental ethic that underlies Scenario 2, how can individual freedom and data about where people live, work, and play be protected given the environmental and quality of life imperatives embodied in Scenario 2?

Exploratory Topic 3
Connected and Automated Vehicles and Travel Behavior Impacts

Alexandra Millonig and Susan Shaheen

Introduction

This briefing paper focuses on travel behavior as it relates to the automation of the transport of goods and people. In this paper, we describe two scenarios that could greatly affect travel behavior given different connected and automated vehicle (CAV) market penetration levels and policy contexts. We present two contrasting scenarios to drive our examination of travel behavior impacts across four cross-cutting issues: (1) economics and the workforce, (2) equity, (3) data access and privacy, and (4) safety and security. The first scenario is primarily market driven with little regulation. The second reflects a more highly regulated world in which the public is much less accepting of automation; not surprisingly, it is also much less market driven. Below we describe our scenario approach and outline key questions across the cross-cutting themes.

Scenarios

As noted, we have created two scenarios to assist us in assessing the travel behavior impacts of automated and connected vehicles in the future. We define these scenarios as: (1) "CAVs on the Rise" and (2) "CAVs Tamed by Policy and People." Please see Figure 1, which positions these scenarios in opposite quadrants based upon two axes: (1) high/low government regulation and (2) strong/weak market forces. We provide a brief discussion of each scenario and outline numerous questions based on the four cross-cutting issues related to travel behavior impacts.

Scenario 1: CAVs on the Rise

CAV services are offered by different competing private companies or private people using their vehicles as an additional source of income. CAVs come in different sizes and models for different purposes (e.g., business vehicles for working, entertainment vehicles) and can be booked at lower rates for regular and/or shared trips or specifically hailed causing higher costs, as fleet management must reschedule trips to serve new requests. Sharing is common for saving costs, but some groups refrain from using shared services with strangers (especially at night), although vehicles are equipped with a surveillance system and users are identifiable—there is even a rating system for co-riders.

Almost everyone is using CAVs also for short trips, even if the traffic is congested or slow, as it is very convenient and time can be spent for different purposes. As the demand for other transport modes has been dramatically decreasing, public transport has been reduced and only a few people use bikes or walk. However, several areas in the city have been reserved for pedestrians and micro-vehicles (like hoverboards and electro scooters) for recreational and retail purposes, although most people rarely go shopping as most purchases are made online. Outside the cities, there is practically no other transport mode used besides CAVs.

In this scenario, "CAVs on the Rise," we explore possible travel behavior impacts across four dimensions: (1) economics and the workforce, (2) equity, (3) data access and privacy, and (4) safety and security. In each area, we pose key questions in the context of associated impacts, which could result from the "CAVs on the Rise" scenario.

Economics and Workforce

In this scenario, many new business models related to transport services will be developing, especially in the private sector. How will the increased demand for private CAV services and related businesses (e.g., maintenance, traffic management) affect different types of professions in the transport sector?

Personalized requests and increasing individualization will open new chances for start-ups and smaller businesses, but at the same time, few globally acting companies will dominate the market. How will this affect the chances and barriers for workers? Which social groups might benefit and which could be disadvantaged (e.g., competences/education levels or socio-demographic characteristics)?

What would be the consequences of a highly competitive transport market for the definition of work (e.g., hourly employee versus salaried employee, quality of work, work-life-balance)? Could this lead to a growing amount of uncertain jobs? Who might be affected?

Equity

How would such a transportation system impact socioeconomic disparity? Is there a risk of increasing social gaps as individuals with financial resources or in powerful positions receive a higher priority on their trips, while others may have to accept longer commutes due to limited resources and longer travel times? How might this impact health due to reduced physical exercise and social contacts due to long commutes?

Would competing services facilitate accessibility for all groups of people, including previous non-drivers like older adults, children, or people with disabilities? Or could access to transport become more restricted with no more alternatives being available, as private operators might discriminate or ban specific groups from using their services?

With CAVs being the dominant transportation mode, could this result in discrimination of other road users? For instance, could pedestrians and cyclists be restricted to limited areas to avoid "disturbances" with connected fleets)?

Data Access and Privacy

Social groups with limited financial backgrounds or long travel distances may be forced to give up privacy and sell their data (e.g., when and where they travel, with whom, reveal their activities during travel) to be able to get around. This could also impact young people who may not take this seriously. What could be the consequences of such a development?

With customers becoming more and more transparent, service providers can use this information to either restrict or ban certain groups (discriminatory practices) or manipulate their behavior by putting them on specific routes or exposing them to specific information. What could be the effects?

People who are especially concerned about their privacy will find it challenging to protect their data and might greatly reduce their transport needs as a result. How will the users' trust in how the different service providers are handling their data impact their freedom of choice, especially in areas where there are just one or two providers?

Safety and Security

Will personal safety become a matter of financial resources, when CAVs get to "decide" who to sacrifice in the case of an unavoidable accident (e.g., higher worth buys you safety/security)? How can the personal perception of safety and security affect the behavior of specific groups? For example, women might avoid booking cheaper shared trips at night time (causing limited access), or active mobility could perceived be as much less safe, resulting in longer-term health issues.

Some groups are more reliant on transportation access than others, (e.g., commuters or emergencies). Which groups are especially at risk, if the connected transport system fails due to malfunction or a cybersecurity breech?

Scenario 2: CAVs Tamed by Policy and People

Due to international commitments to dramatically improve climate conditions and reduce the consumption of land and resources, governments have implemented effective measures on transportation to significantly decrease traffic volumes (e.g., road pricing). This development is supported by considerable changes in the production sector (e.g., emerging technologies like automation and 3D-printing accelerate local productions and teleworking becomes common). Further, a paradigm shift occurs towards more sustainable, local lifestyles. This results in a landscape of smaller communities where people spend most of their time, but they are highly connected to other parts of the country through telecommunication.

If possible, people follow their daily routines in the close vicinity, working in local community centers offering teleworking spaces and covering the majority of the distances by walking or using shared bikes or microvehicles (e.g., hoverboards and electro scooters). Smaller CAVs are only rarely used for passenger transport (e.g., people with disabilities or to reach larger hubs for mass transportation) and are strongly regulated as the use is only granted to specific groups, but are common for transporting goods, as people prefer to get their purchases delivered than carry them. For longer distances, automated public mass transport is used, but people usually avoid having to travel longer distances on a regular basis. Only a small elite employ private AVs, mainly to display their status (as these are very expensive) and distinguish themselves from other citizens.

We also explore possible travel behavior impacts across four dimensions in this second scenario: "CAVs Tamed by Policy and People": (1) economics and the workforce, (2) equity, (3) data access and privacy, and (4) safety and security. In each area, we pose key questions related to associated impacts, which could result from the second scenario.

Economics and Workforce

The automobile sector has shifted its focus from vehicles for private transport to community vehicles for special services and smaller vehicles for the transport of goods, many of them are produced in the region. In parallel, the construction of walking and cycling infrastructure and a variety of walking aids (e.g., small transport robots) create new businesses. How would such developments affect professions in the transportation sector?

With jobs becoming available in the vicinity due to teleworking, specific groups (e.g., people taking care of family members, disabled people) have improved job access. At the same time, the local community can only offer a limited amount of jobs and professions, which may force people to move to find a job. Which jobs and competences may benefit more or less in such a scenario?

Teleworking at local community centers and at home enables people to have more flexible working times, but it also can interfere with their private life, affecting their work-life-balance and productivity. What could be the consequences for work, families, and communities?

Equity

Reduced travel distances also imply that access to several facilities (work, education, leisure) cannot be compensated by "virtual trips," which are not accessible in the community. Some groups may therefore be forced to travel. Which groups will most likely be affected by this? Is there a risk for certain groups that are disadvantaged?

Some groups are more privileged than others in this scenario (e.g., by regulations or private resources). Could this contribute to increased social disparities in local communities, leaving individuals not eligible for public support and without the financial resources behind?

Experience shows that frequently encountering unfamiliar people and groups increases tolerance. Is there a risk that fairly closed communities may lead to increasing tensions between different local communities, resulting in psychologically perceived in- and out-groups, even causing instability in a region or nation?

Data Access and Privacy

With daily activities being concentrated within a small spatial range, the boundaries between different aspects of life (e.g., work and private life, family, and community) become blurred. As people also put a lot of trust in communities, the handling of sensitive personal or professional data may become negligent. What are the risks and which groups may be more prone to experience disadvantages?

Strong local communities can increase the sense of security, but they are also known for a high level of social control. As people know each other, each movement and delivery can be registered by people in the surroundings. How can close communities impact the freedom of individuals to get around and keep their privacy?

For efficiency reasons, regional companies strive to combine the production of goods and delivery of services in the region. These businesses gain access to a very rich and comprehensive database about their local customers. What could be positive or negative consequences for consumers?

Safety and Security

As CAVs have not succeeded in being widely accepted and local transport (walking and cycling supported by partially automated aids) has strongly increased, the positive effect of CAVs on road safety is not achieved. What are the consequences to no improvement in road safety or more but less severe accidents?

Longer distances are much less traveled; hence, the capacity of transporting large amounts of people or goods is considerably reduced. What could be the impacts in the case of a natural disaster or terrorist attack when fast evacuation or quick supply of goods is vital?

Exploratory Topic 4
Connected and Automated Vehicle Impacts of Stakeholder Responses

Satu Innamaa and Matthew W. Daus

Introduction

This briefing paper focuses on the interaction between various regulatory approaches to CAVs and various socioeconomic impacts and issues due to different stakeholder actions. The briefing identifies: (1) stakeholders in the CAV implementation, technology and policy framework evolution process; (2) CAV governance scenarios across a spectrum of potential market forces versus government regulatory controls, and various outcomes of CAV implementation under such scenarios; and (3) key socioeconomic impacts related to the cross-cutting themes: (1) economics and welfare, (2) social equity, (3) data access and privacy, and (4) safety and security.

Stakeholders

The introduction of CAVs will influence many different types of stakeholder groups, and stakeholders may undoubtedly conversely initiate, react and/or mold policy and CAV frameworks—on both the public side (as constituents and interest groups) as well as on the private side (as consumers of private company services and products). Stakeholders can be grouped into categories that include: (1) public and quasi-public entities; (2) users or impacted people or entities; (3) automakers; (4) private mobility companies; and (5) technology companies. In terms of governance and the scenarios identified below and in this briefing paper, the influence of the public versus the private sector will be highlighted as the two major categories. Other subcategories that will be identified include organizations that represent groups of stakeholder interest groups (for example, technology industry think tanks, and non-profits that represent or further the interests of groups of consumers or issues). Such groups, to name a few, could include: representation of privacy protections or transport modes; private trade organizations representing industries or owners; constituent interest groups representing causes that promote sustainability or disability rights; and even organizations that represent numerous local or regional governments.

The identification of as many stakeholders as possible is critical, as outreach to these groups to ascertain the socioeconomic impacts of CAVs will help not only to identify the research needs, but also to conduct further research by working with such groups to collect and analyze data from as many diverse perspectives as possible. In terms of public and quasi-public stakeholders, groups would include, of course, government agencies, as well as quasi-public entities, like economic development, tourism bureaus and airports. Users or impacted people or entities would include not just passengers of CAVs, but also those who would interact with CAVs, like bicyclists, pedestrians, drivers of conventional cars and interest groups that represent their viewpoints. In terms of automakers, the nuances and subdivisions of this vast industry will be further identified as there are competing stakeholders not just in terms of manufacturers, but component parts, systems, dealers and advertisers, making up the vehicle industry ecosystem. Private mobility companies affected by CAVs include competing modes and sub-modes, such as transportation network companies, taxicabs, bikeshare and microtransit, as well as future entities and joint ventures that are or may be developing (i.e., subdivisions or wholly owned spin-offs from tech companies or automakers that will be developing multimodal mobility services to supplement and/or promote the introduction and use of CAVs). Finally, technology companies, which are evolving in terms of their function and reach, include not just internet providers, smartphone application and big data software or platform related service providers, but also telematics or safety equipment industry entities, or niche industry providers (e.g., taximeter manufacturers).

Scenarios

Two scenarios can assist in identifying key research needs with respect to stakeholder impacts on CAVs in the future. These scenarios are (1) "CAVs on the Rise"; and (2) "CAVs Tamed by Policy." The figure below positions these scenarios in opposite quadrants based upon two axes: government regulation high/low versus market forces strong/weak. In Scenario 1, the locus of control is on the private sector and, in Scenario 2, on the public sector. Both scenarios include assumptions on high penetration of CAVs in mixed traffic, and a high level of automation (SAE 4–5). For the identification of future research needs, the aspects of these two extremes should be analyzed. Figure 3 describes the two scenarios and addresses potential impacts, challenges and concerns relating to four cross-cutting themes: (1) economics and welfare, (2) social equity, (3) data access and privacy, and (4) safety and security.

Scenario 1: CAVs on the Rise

In Scenario 1, regulators choose to offer minimal intervention for the provision of mobility services. This approach may result in a wider array of innovative services being developed that may not necessarily serve the best interests of all segments of society, and could present more safety risks.

The basis of the transport system relies on private competing mobility services and privately owned AVs; hence, the public transport service offering would be reduced. Different mobility services include carsharing and ridesourcing/transportation network companies. The ecosystems behind these services also include meta-operators for mobility service concepts, payments, etc. Traveler services include infotainment, in-car-work enabling services (e.g., texting, email and teleconference) and parking services for private AVs.

Economics and Welfare

In Scenario 1, there could be high job elimination or re-classification for many for-hire drivers and other

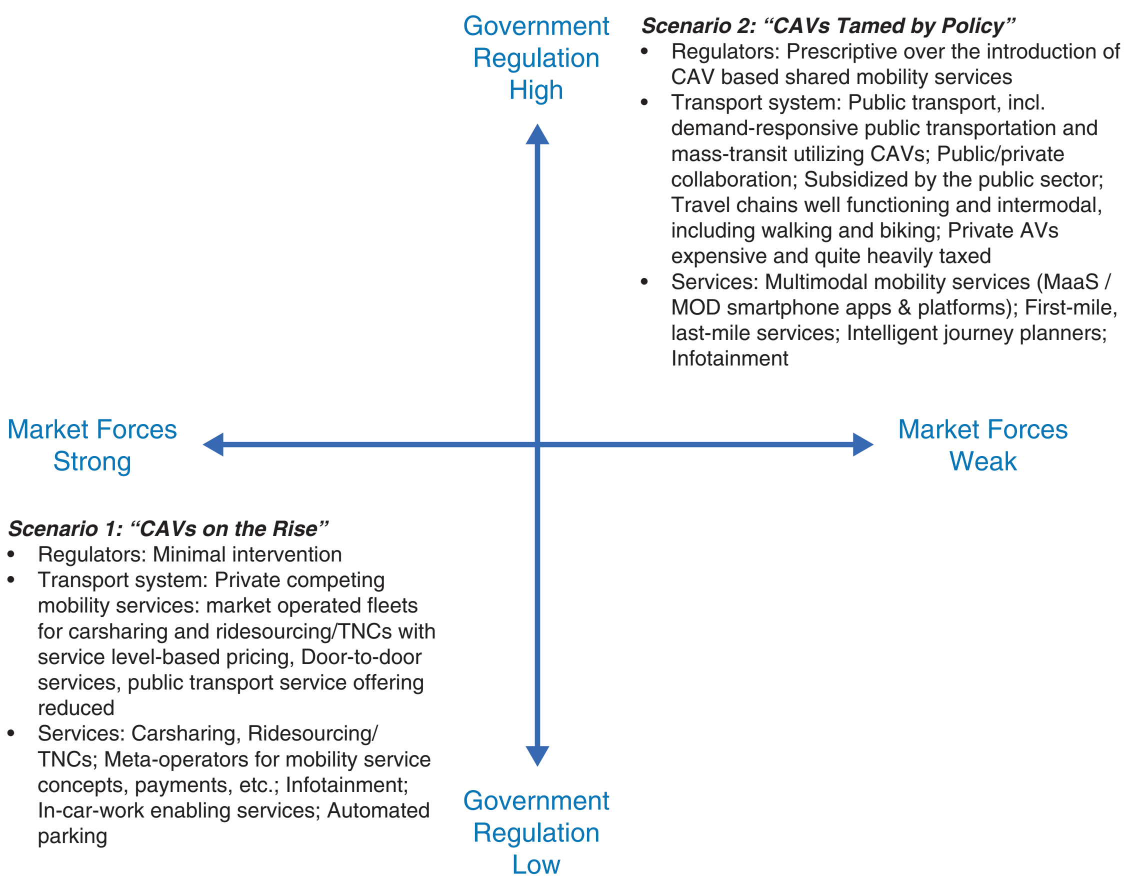

FIGURE 3 Impacts of automated and connected vehicles on stakeholders.

mobility operators (buses, etc.). In addition, there could be changes in the employment responsibilities and work descriptions for the on-the-job drivers, as driving is replaced by other activities while the car is driving to its destination. If there is an increase in unemployment, it affects transport demand indirectly because reduced income causes loss of ability to buy/pay for transport. Is employment support needed for the most affected labor groups due to job loss from vehicle automation? How can we effectively support affected job classes to adapt such employment opportunities to the advent of automation?

The impacts on the make-up of the workforce needed could directly affect the income of the transport service providers. In addition to the savings related to driver costs, by increases in vehicle utilization of CAV-based services, operating costs may be reduced and profitability may therefore increase. However, it is unclear whether passengers will benefit from reduced fares as a result of these decreased costs.

In Scenario 1, innovative mobility businesses emerge in a variety of different service models and providers in the private sector. Ecosystems emerge to facilitate end-user services. Consequently, there will be an increase in workforce demand for service provision and service concept development, fleet management, etc. It is likely that there will be a large number of small service operators in addition to large, even global operators. In this scenario, there is a possibility for additional income for citizens via the offering of private vehicles for carsharing or ride-sourcing services. How can we support innovations (e.g., policy, training) that create jobs that benefit from CAV introduction?

In Scenario 1, outside-city-center malls are popular for commercial services. There are also cost-efficient delivery services to support shopping in them. Can all citizens access these services?

Social Equity

In Scenario 1, private mobility services may not be affordable for all, or may be subsidized in the short term and then could become unaffordable for many. The use of services will include also indirect costs (e.g., it may include a requirement for access to smartphones or similar platforms) and the use of mobile payment services. This scenario may cause social inequities. There may also be a variety of enhanced service-levels resulting from higher prices, which could further increase inequities. There is a risk for the selection of customers if the service is banned for some. The challenge is how we can guarantee affordable mobility for all citizens (all income classes and user groups). What role will or should private equity subsidies play in both the short-term and long-term provisions of services?

As public services have largely been replaced by competing private businesses in this scenario, transport options for people with special needs (e.g., wheelchair users) have become quite expensive, as the vehicles require specific equipment and the target group is comparatively small. This development might be compensated by, for example, advocacy groups collecting donations to support people in need, or insurance companies offering premium reductions or other incentives to facilitate such services. This approach would require a paradigm shift as such services are now viewed as involving increased risks and premiums. What could be the potential solutions provided, who would offer these solutions, and what would the consequences be for different social and other groups?

There is a risk of regional inequity in service offerings if market forces focus the service provisions only on areas where the profit margin is greater and there are no services for areas with low demand where service provision would be non-profitable. There is also a risk for unbalanced routing via different neighborhoods in navigation if routing scenarios can be influenced by payments to the navigation service provider. On the other hand, in Scenario 1 with a larger number of smaller vehicles and more flexible routes, there may also be more opportunities for network level optimization of traffic than in Scenario 2, with more fixed routes. How can we manage the equitable provision of mobility across regions?

Other key questions include: What are the objectives for different private stakeholders in the mobility sector? Are there conflicting interests? What are the key areas we need to understand in CAV shared mobility services to further benefit citizens and businesses? How can we balance the benefits of the private sector and of cities in the regulatory environment in which they are deployed?

Data Access and Privacy

In Scenario 1, the private service providers collect big mobility data from their customers, and may engage in consumer profiling. There is little anonymity/privacy for travelers as they are identified when utilizing such services, and their mobility habits may be monitored. Mobility service providers may have additional business interests and revenue streams that result by vending the data or information retrieved from mobility data. On the other hand, these datasets are unlikely to be openly available anytime soon absent intervention. There is a high demand for cybersecurity services. Some of the questions asked will include whether private service providers collaborate to develop industry standards or protocols (best practices) for the ownership, licensure and dissemination/use of data? Will the tug-of-war over data ownership, use and privacy be resolved by private industry litigation or public and private contractual agreements that evolve without any government regulatory interference or intervention? It is also quite possible that changing business relationships (mergers/acquisitions), joint ventures and mutual investment partnerships between technology/software companies, auto manufacturers and mobility providers could shape the data/privacy framework independent of government involvement.

Safety and Security

In Scenario 1, the users of CAVs may be better protected than other road users in mixed traffic. The crash risk per distance traveled is decreased, but increase in traffic volumes and mileage may increase exposure to crashes, reducing the overall safety impact. Driverless ridesourcing may compromise the security of the travelers or at least their feeling of safety. Market forces, in terms of private concerns for liability exposure and safety risk, could dictate a manufacturing paradigm or scheduling for the mix of CAV fleets. To this end, will private companies decide that it is in their best interests economically—as well as for the safety and security of passengers, pedestrians and other motorists—to have all vehicles on the road be of the same SAE level (e.g., no mix of lower and higher automation levels)? In Scenario 1, the economic interests of the private sector may lean towards what some view as more safety risks by CAV entry into urban markets, as opposed to less profitable implementation in areas where there are reduced safety risks—such as closed communities (e.g., amusement parks, retirement communities, college campuses). Is there a real possibility of the development of safety and cybersecurity standards by the private sector, internationally or domestically in the United States or the European Union?

Scenario 2: CAVs Tamed by Policy

In Scenario 2, regulators are more prescriptive than in Scenario 1 over the introduction of CAV shared mobility services, perhaps resulting in constraints on innovation in transport provision, but with a more defined vision over how such services should be used to improve safety and mobility for city residents and businesses.

The basis of many transport systems rely on public transport, which includes demand-responsive public transportation and mass-transit utilizing CAVs. Travel chains are well functioning and may be intermodal, including walking and biking. There is public/private collaboration, and transport is subsidized by the public sector to ensure a minimum level of mobility services to all people. Private AVs are expensive and quite heavily taxed. Traveler services include multimodal mobility services—Mobility-as-a-Service (MaaS) or Mobility on Demand (MOD) smartphone apps and platforms—first-mile, last-mile services; intelligent journey planners; and infotainment.

Economics and Welfare

In Scenario 2, it is likely that there are slower and more deliberate job protections (than in Scenario 1) due to labor organization input and legislation to protect workers, or that unionization is allowed and workers' rights are enhanced. Still, there will be changes in workforce needs. Which work positions will be reclassified or preserved, and are substantially different skills needed for those reclassified positions (e.g., elder care or paratransit specialists to assist in vehicle ingress/egress, school bus matrons, or customer service assistants to guard against passenger misconduct)?

The workforce impacts will affect the income of the transport service providers. In addition to the savings related to driver costs, by increasing vehicle utilization of CAV-based services, operating costs can reduce and profitability may therefore increase. However, the changes in the transport system have also indirect impacts on the public bodies to provide subsidized transport services as fewer private vehicles lead to lower tax income, which has an effect on how to fund subsidies.

There is an increased workforce demand for operating and developing demand-based and other CAV-based public transport services. A workforce is also needed for development of different easy-to-access and easy-to-use information services related to them. In addition to public transport services, there may be public–private collaborations in provision of the mobility services. In Scenario 2, there may be less work in the private mobility service sector, than in Scenario 1, and also fewer but larger service operators.

In Scenario 2, transport hubs serve as important service hubs and are also used as commercial market places.

Social Equity

In Scenario 2, basic transport services are easier to guarantee for all regions and social classes (low-cost mobility options with mass-transit), including rural areas, than in Scenario 1. These mobility services require the use of smartphone applications and smart cards, which may be challenging for older adults. The basic service fee for public transport is the same for all. However, there may be additional mobility options, such as "first-mile, last-mile" services, with additional fees that may cause social inequity. In this scenario, there is a large difference in mobility for the affluent (private AVs) and the rest of society (public transport based mobility services). What role will or should public subsidies play in both the short-term and long-term provision of services?

In Scenario 2, with public sector transport operators, it may be easier to achieve equity among neighborhoods in terms of traffic management, as political decisions can be better made by analyzing routings of traffic flows, than in Scenario 1. There may also be better compliance with network level optimization of road network use.

A distribution of tariffs may allow low-income neighborhoods that are poorly served by public transportation to be served by new innovative CAV-based mobility services at lower costs, whereas areas with good quality public transportation links and infrastructure that support active travel, may have higher tariffs on new mobility services to limit their use. In this scenario, there may be subsidized delivery services to support healthy living (e.g., food) for all.

One of the key questions is how policies and regulation can support introduction of private CAV services and solutions that supplement the public transport and support the mobility strategies of municipalities (e.g., use of active modes of transport). How can CAV-based shared mobility services be supported by regulation and planning? In addition, what role should the government play in the formation of laws and regulations that impact or distribute economic costs or obligations on industries, modes and/or sub-modes of transport services to provide wheelchair-accessible service to people with disabilities—in the private CAV transport market? For example, much debate has occurred in the United States following the passage and implementation of the Americans with Disabilities Act, and the U.S. Department of Transportation's implementing "equivalent service" standards. These laws and regulations exempted taxicabs from providing wheelchair-accessible vehicle (WAV) services; however, local efforts to use taxicabs and for-hire vehicles to provide WAV services, when not mandated by federal law, are impeded by the "equivalent service" standards, which treat less-than-perfect service as discrimination. Such exacting or demanding service standards may not be fully achievable without significant subsidies to offset WAV ramp retrofitting and increased insurance costs. In the European Union, regulation imposes the rights of passengers, specifically mentioning equal rights also for those with a disability or reduced mobility.

Data Access and Privacy

In Scenario 2, public authorities are the owners or licensed users of mobility data. Anonymity/privacy of travelers can remain for some public transport services, but identification of the user is required for some services. There is more potential for the provision of open data with respect to mobility than in Scenario 1. In Scenario 2, there is a similarly high demand for cybersecurity services as in Scenario 1. In Scenario 2, one might question what the legal data paradigm would be in light of freedom of information laws, "right to be forgotten" laws (e.g., the United Kingdom), and the impact on public-private MaaS/MOD partnerships. The role that legislation will or could play to resolve and manage competing interests and concerns about data ownership and use could have a stabilizing effect on private business ground rules and expectations. However, one could argue to the contrary that government regulation of data could undermine the economic underpinnings or motivations for companies to enter and develop innovative products and services, if the right to access private data or ownership is undermined or minimized.

Safety and Security

In Scenario 2, the crash risk per distance traveled may be reduced for CAVs and lower traffic volumes in terms of the number of vehicles possibly decreasing exposure to crashes (i.e., a decrease in relative crash risk) for all road users (including vulnerable road users). Driverless public transport in Scenario 2 may compromise the security of the traveler or at least their perception or feeling of safety. In this scenario, government regulators could control or dictate the CAV mix on the streets, and may determine whether the safety and security of passengers, pedestrians and other motorists will be enhanced by having all vehicles on the road be of the same SAE level (e.g., no mix of lower and higher automation levels), or by restricting the use of various SAE levels to certain high, low or mixed density areas. Can or should the government control CAV rollout as a function of land use or urban planning, with safety as a priority? If so, what are the risks or safety concerns associated with implementation of CAVs in urban, versus suburban, rural and closed or quasi-closed communities (e.g., amusement parks, retirement communities, college campuses)? Finally, is there an ideal governance structure for the development of uniform laws, rules and regulations addressing safety and cybersecurity standards by the public sector, internationally or domestically in the United States or the European Union?

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APPENDIX C

Program

Socioeconomic Impacts of Automated and Connected Vehicles

Sixth EU–U.S. Transportation Research Symposium

Organized by the
European Commission
Transportation Research Board

June 26–27, 2018
Hotel NH Brussels Bloom
1210 Saint-Josse-ten-Noode
Brussels, Belgium

Day 1, Tuesday, June 26, 2018

07:30 a.m. Registration and Breakfast

08:30 a.m. **Welcome and Opening Remarks by Lead Delegates**

Clara de la Torre, Director, Directorate Transport, Directorate-General for Research and Innovation, European Commission

Robert Missen, Head of Unit, Innovation & Research, Directorate Investment, Innovative & Sustainable Transport, Directorate-General for Mobility and Transport

Neil J. Pedersen, Executive Director, Transportation Research Board, National Academies of Sciences, Engineering, and Medicine

Alasdair Cain, Director of Research, Development and Technology Coordination, Office of the Assistant Secretary of Research and Technology, U.S. Department of Transportation

Purpose and Scope for the 6th EU-U.S. Symposium: Socioeconomic Impacts of Automated and Connected Vehicles

Barbara Lenz, Head of Institute, Institute of Transport Research, German Aerospace Center, *Cochair*

Susan Shaheen, Adjunct Professor and Co-Director, Transportation Sustainability Research Center, University of California, Berkeley, *Cochair*

09:00 a.m. **Presentation of the Symposium White Paper**

Johanna P. Zmud, Planning Division Head and Senior Research Scientist, Texas A&M Transportation Institute

Nick Reed, Head of Mobility R&D, Bosch

09:45 a.m. Morning Refreshment Break

10:15 a.m. **Setting the Scene: Designing Fair Transportation Systems**

Karel Martens, Associate Professor, Faculty of Architecture and Town Planning, Technion—Israel Institute of Technology

Michael F. Ableson, Vice-President, Global Strategy, General Motors LLC

11:00 a.m. **Review of the Four Exploratory Topics**
The participants will address the four exploratory topics in four consecutive working group discussions on cross-cutting themes; per cross-cutting theme, four parallel sessions will be organized, each focusing on one specific exploratory topic.

Exploratory Topic 1: Freight—Impacts on People
Timothy Papandreou, Founder, City Innovate
Barbara Lenz, Head, Institute of Transport Research, German Aerospace Center

Exploratory Topic 2: Places Where People Work, Live, and Play
Alex Karner, Assistant Professor, School of Architecture, University of Texas, Austin
Marcin Stepniak, Polish Academy of Sciences, Warsaw, Poland

Exploratory Topic 3: Impact of Automation on Travel Behavior
Alexandra Millonig, Senior Scientist, AIT Austrian Institute of Technology
Susan Shaheen, Adjunct Professor and Co-Director, Transportation Sustainability Research Center, University of California, Berkeley,

Exploratory Topic 4: What Do Stakeholders Do?
Matthew Daus, Partner, Windels Marx Lane and Mittendorf, LLP
Satu Innamaa, Principal Scientist, VTT Technical Research Centre of Finland Ltd.

12:30 p.m. Networking Lunch

13:30 p.m. **Working Group Discussion on Cross-Cutting Theme 1: Economics and Welfare Issues**

15:15 p.m. Afternoon Refreshment Break
(Notetakers consolidate information and prepare key points for report out.)

15:45 p.m. **Working Group Discussion on Cross-Cutting Theme 2: Equity**

17:30 p.m. **Wrap-up for Day 1**
Notetakers consolidate information and member(s) of the planning committee rehearse(s) briefly the four exploratory topics.

18:00 Mix & Mingle: Networking Reception

Day 2: Wednesday, June 27, 2018

07:30 a.m. Breakfast

08:00 a.m. **Re-Review of the Four Exploratory Topics:**
Participants meet immediately in the working groups, where the four exploratory topics will be refreshed before starting the first group discussion on Cross-Cutting Theme 3.

Exploratory Topic 1: Freight—Impacts on People
Exploratory Topic 2: Places Where People Live, Work, and Play
Exploratory Topic 3: Impact of Automation on Travel Behavior
Exploratory Topic 4: What Do Stakeholders Do?

08:30 a.m. **Working Group Discussion on Cross-Cutting Theme 3: Data Access and Privacy**

10:15 a.m. Morning Refreshment Break
(Notetakers consolidate information and prepare key points for report out.)

10:45 a.m. **Working Group Discussion of Cross-Cutting Theme 4: Safety and Security**

12:30 p.m.	Networking Lunch (Notetakers consolidate information and prepare key points for report out.)
13:30 p.m.	**Report Out on the Working Group Discussions** Facilitated by members of the planning committee. Four testimonies given by one volunteer for each exploratory topic. Moderator consolidates information and prepares key points for closing debate (last-chance assertions).
15:00 p.m.	**Closing Debate: Last-Chance Assertions** Facilitated by a member of the planning committee.
15:45 p.m.	**Next Steps and Closing Remarks by Lead Delegates** Clara de la Torre, Director, Directorate Transport, Directorate-General for Research and Innovation, European Commission Robert Missen, Head of Unit, Innovation & Research, Directorate Investment, Innovative & Sustainable Transport, Directorate-General for Mobility and Transport Neil J. Pedersen, Executive Director, Transportation Research Board, National Academies of Sciences, Engineering, and Medicine Alasdair Cain, Director of Research, Development and Technology Coordination, Office of the Assistant Secretary of Research and Technology, U.S. Department of Transportation
16:00 p.m.	Adjourn & Safe Travels

APPENDIX D

Symposium Attendees

Michael Ableson
General Motors
United States

Jameson Auten
Kansas City Area Transportation Authority
United States

Robert Bertini
University of South Florida
United States

Marco Boero
Softeco Sismat
Italy

Clarrissa Cabansagan
TransForm
United States

Wendy Callaghan
American International Group, Inc.
United States

Annie Chang
SAE International
United States

James Corless
Sacramento Area Council of Governments
United States

Yannick Cornet
University of Zilinja
Slovakia

Anita Cozart
PolicyLink
United States

NOTE: Along with each attendee's institutional affiliation, his or her country of origin is listed.

Matthew W. Daus
Windels Marx Lane & Mittendorf
United States

Natalia de Estevan-Ubeda
Independent
Spain

Naomi Doerner
City of Seattle, Washington
United States

Philippe Gougeon
Valeo
France

Johann Gwehenberger
Allianz Insurance
Austria

Robert C. Hampshire
University of Michigan
United States

Dirk Heinrichs
Technical University Berlin
Germany

Steven Higashide
TransitCenter
United States

Justin Holmes
Zipcar
United States

Satu Innamaa
VTT Technical Research Centre of Finland
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Randall Iwasaki
Contra Costa Transportation Authority
United States

Alex Karner
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Barbara Lenz
German Aerospace Center
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Dalia Leven
AECOM
United States

Marius Macku
Uber
United States

Karel Martens
Technion—Israel Institute of Technology
Netherlands

Natasha Merat
University of Leeds
United Kingdom

Dimitris Milakis
Delft University of Technology
Greece

Alexandra Millonig
AIT Austrian Institute of Technology
Austria

Massimo Moraglio
Technical University Berlin
Italy

Timothy Papandreou
City Innovate
United States

Pavithra Parthasarthi
Puget Sound Regional Council
United States

Mike Pinckard
Taxicab Limousine and Paratransit Association
United States

Evangelia Portouli
ICCS
Greece

Cristina Pronello
Sorbonne University
Italy

Tina Quigley
Regional Transportation Commission of Southern Nevada
United States

Nick Reed
Bosch
United Kingdom

Andrea Ricci
Institute of Studies for the Integration of Systems (ISINNOVA)
Italy

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Austria

Susan Shaheen
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University of South Carolina
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Nikolas Thomopoulos
University of Greenwich
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