Lecture Notes in Mobility

Gereon Meyer · Sven Beiker *Editors*

Road Vehicle Automation 5

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Road Vehicle Automation 5

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Preface

As the field of road vehicle automation continues to evolve at a seemingly accelerated pace, experts and the general public alike get to experience the first public deployments and also setbacks of this very promising technology. We all learn from those diverse practical experiences through automated shuttle services, fleets of automated ride-hailing vehicles, and increased levels of automation in advanced driver assistance systems. And in this, it also becomes very evident that it will be essential to reach societal consensus about the safety level expected from automated vehicles, translate this into standards for the technical systems, and apply those standards in legislation. Probably, this task should be as important for policy makers in mapping out regulation as it is for businesses to generate excitement around the promise of shared automated vehicles.

We are excited to say that the multifaceted content of the books on Road Vehicle Automation that we have published over the past 5 years as part of the Springer series Lecture Notes in Mobility has contributed already significantly to understanding these issues in a comprehensive way. We continue to be amazed by the topics discussed in the papers, the enthusiasm and diligence of the authors, and the great overview on the topic of vehicle automation, which we always get—it is an honor to edit this book, and we thoroughly thank all contributors and supporters. Through the efforts of so many, this annual publication has become literally the log for the automated driving movement, which probably many of us will consult well into the future and remember how we actually got to where we will be with automated driving in 2020, 2035, 2030, and beyond.

Today, we are proud to present the fifth edition of the Road Vehicle Automation books. This time we have a comprehensive overview of activities in the USA, Europe, and Asia; we also get invaluable insights into the technology, business, policy, and human factors of automated driving. The chapters are all based on oral and poster presentations of the Automated Vehicles Symposium (AVS) 2017 in San Francisco, California (USA). We feel deeply indebted to Jane Lapin, Steve Shladover, and Bob Denaro for their great support of organizing this outstanding conference and afterward in preparing this book; their foreword is very much appreciated. Of course, this book would not be possible without the immense work done by Jan-Philip Schmidt and Petra Jantzen from Springer and Sebastian Lugert from VDI/VDE-IT as they made sure everything is on schedule so that you can hold this book in your hands today. Kind support by the Association of Automated Vehicle Systems International (AUVSI) is greatly appreciated as well.

And finally, a big thank-you goes again to all authors, who very often in their spare time write and again edit their contributions, which is what makes this publication what it is—one of the most-read publications in automated driving of our times: For the first four volumes, Springer has counted almost 200 thousand chapter downloads, and access is provided by 300 libraries around the globe.

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May 2018

Contents

Part I Public Sector Activities

Part II Human Factors and Challenges

Part III Technology, Energy and Business Perspectives

Part IV Vehicle Systems and Technologies Development

Part V Transportation Infrastructure and Planning

Introduction: The Automated Vehicles Symposium 2017

Steven E. Shladover, Jane Lappin and Robert P. Denaro

Abstract The 2017 Automated Vehicles Symposium built on the successes of the predecessor meetings, with an even larger and more diverse roster of participants and a broader selection of breakout sessions. The plenary and poster presentations and breakout discussions continued to provide the meeting participants with the most up-to-date and authoritative information about the current international state of development and deployment of road vehicle automation systems, making this the essential meeting for industry, government and research practitioners in the field.

Keywords Road vehicle automation · Road transport automation
Automated vehicles · Autonomous vehicles · Self-driving vehicles

1 Overview

The 2017 Automated Vehicles Symposium was organized and produced through a partnership between the National Academies of Science and Engineering Transportation Research Board (TRB) and the Association for Unmanned Vehicle Systems International (AUVSI), continuing the pattern established in the three preceding years. This meeting was organized to serve their constituencies' interests

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in understanding the impacts, benefits, challenges and risks associated with increasingly automated road vehicles and the environments in which they operate. It brought together key government, industry and academic experts from around the world with the goal of identifying opportunities and challenges and advancing automated vehicle (AV) and highly automated driving (HAD) research across a range of disciplines.

The symposium took place over five days, 10–15 July, 2017 with three days of core activities and ancillary sessions on the first and last days. The morning plenary sessions included presentations from the public sector, automakers and suppliers and research institutes and the afternoons were devoted to twenty-four breakout sessions for deeper investigation and discussion of selected topics. Receptions and poster sessions followed the close of the breakout sessions on Tuesday and Wednesday afternoons.

The breakout sessions were each organized by committees of volunteers to address a wide range of topics. Five of the breakout sessions spanned both afternoons of the Symposium, providing more time for exploration in greater depth and breadth:

- Public Transport and Shared Mobility
- Human Factors in Road Vehicle Automation
- Trucking Automation
- Enabling Technologies
- Research on Behavioral Responses to AVs.

The other nineteen breakout sessions covered a single afternoon each:

- An AV crashes: What Happens Next?
- Urbanism Next: AV Effects on Urban Development
- Effects of Vehicle Automation on Energy Usage and Emissions
- Data Sharing Models and Policy
- Artificial Intelligence and Machine Learning for Automated Vehicles: Exploring Tools, Algorithms and Emerging Issues
- Testing Connected and Automated Vehicles: Accelerating Innovation, Integration, Deployment and Sharing Results
- Challenges and Opportunities for the Intersection of Vulnerable Road Users and AVs
- Enhancing the Validity of Traffic Flow Models with Emerging Data
- CAV Scenarios for High-Speed Controlled Access Facilities
- Connected and Automated Vehicle Early Deployment Alternatives
- Aftermarket Systems (ADAS-Related)
- Safety Assurance
- Reading the Road Ahead: Infrastructure Readiness
- Shark Tank: Change is Coming, Who Will Survive?
- Making Automation Work for Cities
- Connected and Automated Vehicles in Traffic Signal Systems

- Legal and Policy Approaches: Finding the Right Balance on Legislating for Automated Vehicles
- Automated Vehicles for People with Disabilities
- Ethical and Social Implications.

The symposium also involved several related meetings that occurred before and following the main meeting:

- U.S. DOT Listening Session
- National Cooperative Highway Research Program panel 20-102, sponsoring research on impacts of connected vehicles and automated vehicles on state and local transportation agencies
- SAE On-Road Automated Driving (ORAD) Standards Committee meeting
- U.S. DOT stakeholder forum on standards needs for automated driving
- Meeting of the TRB Committee on Emerging and Innovative Public Transport and Technologies
- Meeting of the TRB Forum on Preparing for Automated Vehicles and Shared Mobility Systems
- U.S.—Japan—EU Trilateral Working Group on Automation in Road Transportation.

In keeping with TRB practice, the plenary and breakout sessions were planned and produced by volunteers whose expertise and work informed the content of the sessions. In keeping with AUVSI practice, the production of the symposium was professionally managed by dedicated conference and logistics managers. The AVS17 Executive Committee reflected this mix of the two organizations:

Richard Bishop, AUVSI subject matter expert on automation; Richard Cunard, Senior Program Officer, Traffic and Operations Engineer, TRB; Bob Denaro, ITS Consultant, Chair, TRB Joint Subcommittee on the Challenges and Opportunities for Road Vehicle Automation; Jane Lappin, Toyota Research Institute, Past Chair, TRB Intelligent Transportation Systems Committee (AHB15); Jack Pokrzywa, Director, SAE Global Ground Vehicle Standards; Steven Shladover, University of California PATH Program, Chair, TRB Vehicle-Highway Automation Committee (AHB30); Brian Wynne, President and CEO, AUVSI; Lindsay Voss, Senior Program Development Manager, AUVSI.

2 Symposium Attendees

About 1500 registrants participated in the symposium, growing by about 300 people over 2016 and consistent with the growth experienced over the preceding three years of meetings. Attendees represented a wide range of organizations from government and industry to the academic-, public-, and private-sector research communities. One of the strengths of the meeting was the breadth of interests represented, including industry (about 45%), public agencies (about 15%) and academic/research organizations (about 22%). The automobile industry was well-represented with many attendees from Original Equipment Manufacturers (OEMs) and their suppliers.

These participants represented disciplines ranging from engineering to psychology to law. Twenty-seven countries (representing the 20% of the meeting participants who come from outside the U.S.) and forty-three U.S. states were represented among the meeting participants. The largest delegation from outside the U.S. came from Japan, with 65 participants, while South Korea, Canada and Germany all had more than 20 participants and the UK and Australia also had substantial attendance. Consistent with the previous meetings, California, as the host state, had the largest number of attendees from within the U.S., followed by the national capital region (DC, Maryland, and Virginia) and Michigan.

3 Keynote Talks

Malcolm Dougherty, the Director of the California Department of Transportation (Caltrans), welcomed the attendees to California with an overview of the state's history of leadership in research on road vehicle automation. He noted that connected and automated vehicles are mentioned in all transportation legislation in California now. On-road testing of highly automated vehicles under the California DMV regulations began in September of 2014 and currently thirty-six companies are licensed to test AVs in California. In March of 2017 California published draft rules for AV operations, including consideration of testing without a test driver in the vehicle.

Dr. Gill Pratt, CEO of the Toyota Research Institute (TRI), gave the opening plenary address. He defined their basic goals in terms of three rules: (1) Stay on the road, (2) Don't hit anything, and (3) Don't get hit. He noted the challenge for AVs in that current drivers experience one fatality per 100 million miles. Gill addressed the issue of what is "safe enough" when considering automated vehicles. He said that would be up to society, not the automobile manufacturers, but he observed that there is no empathy in society for machine errors compared to apparent societal empathy for human errors.

Gill referred to the Japanese philosophy of kaizen, or continuous improvement introduced in Japan after WWII and embraced by Toyota. He noted that this is not what we are experiencing in the emergence of automated driving. Instead, we are pursuing high-risk/high-reward developments where often when we try, we fail, but sometimes we succeed. This is not kaizen and continuous improvement but instead disruptive development.

In his AVS17 plenary Gil announced a new venture capital subsidiary of Toyota Research Institute in Silicon Valley called Toyota AI Ventures, investing in entrepreneurs who share Toyota's commitment to improving the human quality of life through artificial intelligence, with a focus on automated mobility, robotics, big data and cloud computing. The fund will issue calls for technologies that meet TRI needs.

4 Plenary Panel Sessions

Steven Shladover chaired a plenary panel session on regulations for automated driving systems, with panelists Alicia Fowler from the California State Transportation Agency, James Fackler from the Michigan Department of State, John Bozzella, Association of Global Automakers and John Simpson from Consumer Watchdog.

Richard Bishop chaired a plenary panel session on trucking automation technology developments, with panelists Michael Cammisa from the American Trucking Associations, Max Fuller from U.S. Xpress, Inc., Josh Switkes from Peloton Technology, Alden Woodrow from Uber Advanced Technologies Group, Kelly Regal from the Federal Motor Carrier Safety Administration and Aravind Kailas from Volvo Group North America.

Kelley Coyner chaired a plenary panel session on shared mobility, with panelists Jeff Hobson from the San Francisco County Transportation Authority, Joseph Okpaku from Lyft and Adam Gromis from Uber.

5 Plenary Presentations

Recent Developments in Vehicle Automation Technology:

- Integrating Autonomous Drive into the New Automotive Reality—Maarten Sierhuis, Nissan Silicon Valley Research Center
- Global Scalability of Autonomous Vehicles—Karl Iagnemma, nuTonomy
- Deep Learning and Highly Automated Vehicles—Robert Seidl, Motus Ventures
- Systematic and Data-Driven Approaches to Autonomous Vehicle Testing and Certification—Michael Wagner, Edge Case Research
- PEGASUS: First Steps for Safe Introduction of Automated Driving—Hermann Winner, Technische Universität Darmstadt
- Let’s Move the Security Needle: Think Offensively—Jonathan Petit, OnBoard Security, Inc.

Identifying and Addressing Key Non-Technological Research Questions:

- Regulating Autonomous Vehicles Amid Uncertainty—Nidhi Kalra, RAND Corporation
- Drones, Loops and Robotaxis: A City Roadmap to Our Hyper-Uber Future, Seleta Reynolds, Los Angeles Department of Transportation
- Future of Urban and Autonomous Mobility: Bringing Autonomy On and Beyond the Streets of Boston—Andrey Berdichevskiy, World Economic Forum
- Identifying and Addressing Non-Technical Key Research Questions: Infrastructure—Shailen Bhatt, Colorado Department of Transportation
- Serving the Needs of All through Better Design—Edward Steinfeld, SUNY Buffalo

- Revisiting the Topic—The Future is Autonomous Driving—But Are “We” on a Near Term Collision Course?—Dr. Bryan Reimer, MIT AgeLab.

International Public Sector Activities on Road Vehicle Automation:

- Automated Vehicle Regulation in Europe—Edwin Nas, Netherlands Ministry of Infrastructure and the Environment
- Automated Vehicles in the UK—Phil Blythe, UK Department for Transport
- Korea’s Autonomous Vehicle Policies—Kim Chae-gyu, Director General, Bureau of Motor Vehicles Policy, Republic of Korea
- Drive Sweden: Un Update on Swedish Automation Activities—Jan Hellaker, Lindholmen Science Park AB
- SIP-adus: An Update on Japanese Initiatives for Automated Driving—Yoichi Sugimoto Honda R&D Co., Ltd.
- Public Agency Automated Vehicle Initiatives: European Commission—Gereon Meyer, VDI/VDE Innovation + Technik GmbH.

Public Agency Programs in the U.S.

- Update on U.S. DOT Automation Programs—Kevin Dopart, Intelligent Transportation Systems Joint Program Office, U.S. DOT
- DOE’s Focus on Energy Efficient Mobility Systems—David Anderson, U.S. Department of Energy.

6 Breakout Sessions

The breakout sessions provided opportunities for more in-depth consideration of specific topic areas among groups of people with focused interests in those areas. With smaller groups, they could be more interactive than the large plenary sessions, with ample opportunities for questions and answers and debates. The primary findings from the breakout discussions were reported back to the plenary group on the final morning of the Symposium, in four panels based on thematic groupings. Brief descriptions of those sessions are summarized here. These are derived from the descriptions in the Proceedings of AVS17, published by TRB as *Transportation Research Circular No. E-C232* in April 2018, available at: http://www.trb.org/Publications/PubsTransportationResearchCirculars.aspx.

6.1 User-Related Automated Vehicle Issue Breakout Sessions

6.1.1 Research to Examine Behavioral Responses to AVs

The goal of this session was to identify research needs and develop research approaches, both quantitative and qualitative, for gaining deep insight into behavioral responses to AVs in three priority areas: (1) vehicle ownership and use choices; (2) activity and travel choices—what people do, how often, how they get there; and (3) land use choices—where people choose to live and work. Short presentations introduced key research questions in these three areas. There was also a presentation on the value of time (VOT), which has important implications for land use choices and activity–travel choices. Participants identified and discussed research needs related to the three areas.

6.1.2 Automated Vehicle Challenges; How Can Human Factors Research Help Inform Designers, Road Users, and Policy Makers?

This session focused on the likely consequences of vehicle automation on humans adapting to these new technologies. The session included a panel with four speakers providing remarks and answering questions from participants. The panelists came from industry, government, and academia outside the traditional human factors research community.

6.1.3 Judging a Car by Its Cover and the Human Factors Implications for Automated Vehicle External Communication

Sponsored by the TRB Human Factors in Road Vehicle Automation Subcommittee, this session featured updates on international projects and standardization activities. Currently, road users communicate with one another in numerous ways, including hand gestures, eye contact, turn signals, horns, and the slight movements of a vehicle. Uncertainty exists as to whether highly automated vehicles will be able to perceive and communicate their intent in ways other road users can understand. The session featured three speakers discussing these topics and three interactive exercises.

6.1.4 Challenges and Opportunities for the Intersection of Vulnerable Road Users (VRU) and AVs

This session focused on discussing ways in which AVs could potentially have an impact on the safety and mobility of vulnerable road users (VRUs). The session included two panels: one addressing pedestrian and bicyclist injury data, including safety concerns faced by individuals with disabilities, and a second examining AVs and environmental and planning issues related to pedestrians and bicyclists.

6.1.5 Automated Vehicles for People with Disabilities

This session focused on the transportation needs associated with individuals with disabilities and the application of universal design principles in developing AVs. The session included two panels and interactive discussions providing feedback to inform the U.S. DOT's Accessible Transportation Technologies Research Initiative (ATTRI) and to help develop research topics for the next phase of ATTRI.

6.2 Breakout Sessions on Transportation Applications of Automated Vehicles

6.2.1 Public Transport and Shared Mobility

This two-part breakout session examined vehicle automation technology to support public transit and shared mobility services to enhance mobility for all segments of society. It included eight panels with 30 speakers providing updates on research projects, pilots, and deployment activities.

6.2.2 Trucking Automation: Key Deployment Scenarios

This two-part breakout session focused on key challenges and opportunities associated with the deployment of on-road truck automation. The first session included five presentations on the current state of the art in truck automation and key deployment issues. Two panels followed addressing platooning and highway automation applications. The second session included two deep-dive discussions. The first deep dive examined the deployment of automated trucking technologies with a logistics service provider and the second focused on platooning and highway automation applications.

6.2.3 Aftermarket Systems (Advanced Driving Assistance Systems)

This session examined the role that aftermarket systems, especially ADAS, may play in accelerating the deployment of AVs. The session included speakers from technology start-up companies who discussed the benefits and challenges associated with aftermarket system deployment.

6.2.4 Early Deployment Alternatives

This session examined cooperative adaptive cruise control (CACC) and eco-approach and departure to signalized intersections as two promising early deployment applications. Panelists discussed research and tests being conducted by FHWA, PATH, and industry. Research gaps were identified and discussed.

6.2.5 Shark Tank: Change is Coming; Who Will Survive?

This session examined specific changes that have been advocated or predicted with the deployment of CAVs. Four speakers addressed topics associated with these potential changes. A panel—the "Sharks"—provided a critical review of each topic and discussed technology and market questions, planning and policy implications, and areas for further research.

6.3 Policy and Planning Issues Breakout Sessions

6.3.1 Legal and Policy Approaches; Finding the Right Balance on Legislating for Automated Vehicles

The goal of this session was to bring together the various groups working on or influencing the development and enactment of legislation related to different aspects of testing and operating AVs on public roads. The session included two panels with brief presentations, discussions after each panel, and a small group interactive discussion. The first session focused on organizational approaches. Representatives from nine organizations provided brief descriptions of their AV activities and provided their one policy wish from federal, state, or local governments, or standards development organizations. The speakers rotated around nine tables of participants to provide more details and answer questions. The second policy panel included four legislators discussing AV policy in their states. This panel was followed by moderator-led table discussions of eight AV policy questions. The final part of the session was an interactive roundtable discussion on developing uniform AV legislation.

6.3.2 An AV Crashes; What Happens Next?

This session focused on developing a better understanding of what will happen immediately after a crash involving an AV. Four scenarios were discussed. The first scenario focused on a dark and stormy night, a rock slide, ice, a missing guardrail, and an AV going over a cliff. In the second scenario, a car rear-ends a vehicle stopped at a traffic light. One vehicle is a Level 4 AV driving within its ODD. The other vehicle is not an AV and is operated by a human driver. In the third scenario, an AV under the control of a hacker runs into a human-driven car. In the fourth scenario, a collision occurs because the smart infrastructure fails. The scenarios were discussed by panels of individuals with backgrounds in law enforcement, insurance, product liability, transportation policy, crash reconstruction, and plaintiff and defense expertise.

6.3.3 Ethical and Social Implications of Automated Vehicles

This session focused on challenges in developing and deploying AVs that behave in an ethical manner. Currently, the competing objectives of safety, mobility, and legality sometime conflict in daily driving. The session focused on two general topics. The first topic addressed the ethical and social implications of routine driving. The second topic examined how automakers are responding to NHTSA's guideline on ethical considerations in vehicle automation.

6.3.4 Reading the Road Ahead: Infrastructure Readiness

This session focused on machine vision systems and traffic control devices. The session explored the possible adaptation of traffic control devices for machine vision systems, considered potential machine vision system shortfalls and planned improvements, and examined the role of mapping in navigation and infrastructure identification. The state-of-readiness initiatives were explored and a possible path forward for readiness framework development in North America was discussed.

6.3.5 Making Automation Work for Cities

This session examined the status of automation in cities and metropolitan areas in the United States and Europe, providing a city perspective for CAVs. Speakers in the first part of the session addressed preparing for a new generation of shared collective transportation services while ensuring compliance with key urban policies. Speakers in the second part of the session examined cities' expectations of automation. Participants discussed key elements of an automation-ready framework that helps to meet urban policy goals.

6.3.6 Urbanism Next Workshop: AV's Effects on Urban Development

This session focused on broadening the discussion around AV development and deployment to examine the potential impacts of AVs on e-commerce, the sharing economy, and on urban form, design, and development. The session included high-level presentations and discussion of the possible impacts from AVs on two typical development patterns.

6.3.7 Effects of Vehicle Automation on Energy Usage and Emissions

This session focused on the potential effects of vehicle automation on energy use and emissions. The session included 15 speakers and discussion groups on key topics. The discussion group topics included system-wide models, the impacts of CACC, the impacts of vehicle sharing, the impacts of other technologies, and policy implications and impacts.

6.3.8 Data Sharing Models and Policy

Data exchange among various private- and public-sector entities is critical for the successful widespread adoption of AVs. This session explored governance models and implementation challenges related to data collection, storage, and access. Following an introduction to data sharing issues and activities, speakers in two panels focused on data sharing related to safety and performance and operations and infrastructure.

6.4 Breakout Sessions on Technology Issues

6.4.1 Enabling Technologies for Automated Vehicles

This two-part session focused on enabling technologies for AVs. Speakers addressed technologies for positioning, digital infrastructure, sensing and perception, onboard computing, and cybersecurity. Participants discussed technology needs for different AV applications and areas for further research.

6.4.2 Safety Assurance of Automated Vehicles

This session focused on the need for a Safety Assurance of Automated Vehicles (SAAV). The session featured presentations and panel discussions in two sub-sessions. The four speakers in the first sub-session examined technical approaches on safety assurance. The three speakers in the second sub-session presented societal perspectives on safety assurance.

6.4.3 Artificial Intelligence (AI) and Machine Learning (ML) for Automated Vehicles (AV): Exploring Tools, Algorithms, and Emerging Issues

Automated driving relies on in-vehicle computers that emulate the functions of a human brain in making informed decisions. Such systems may employ AI and sophisticated ML methods to support object tracking and various pattern recognition capabilities. This session provided an overview of some applications that utilized AI and ML tools supporting critical AV functions, as well as highlighted emerging issues and challenges to overcome with such advanced computing tools. This breakout session featured six presentations.

6.5 Breakout Sessions on Operational Issues for AVs

6.5.1 Connected and Automated Vehicles in Traffic Signal Systems

The goal of this two-part breakout session was to explore opportunities for new approaches to control signalized intersections, or more broadly controlled junctions, for connected automated vehicles. The session explored the role of infrastructure and the vehicle in decision making and control decisions, and how vehicles and the infrastructure can cooperate to safely and efficiently operate at the intersections of roadways. This session included nine presentations and follow-up discussions.

6.5.2 Enhancing the Validity of Traffic Flow Models with Emerging Data

This session focused on new simulation techniques and modeling tools for assessing the impacts of AVs on individuals' behavior and traffic flow. For example, AVs may influence lane change positions, lane change execution, vehicle following distance, and acceleration and deceleration profiles. Speakers addressed new simulation and modeling techniques for examining these and other possible impacts.

6.5.3 Connected and Automated Vehicle Scenarios for High-Speed Controlled-Access Facilities

This session focused on scenario planning for CAVs on freeways and managed lanes. It included a panel featuring four speakers providing different perspectives on how CAVs might be deployed on high-speed, controlled-access facilities, including freeways, managed lanes, and toll roads. These types of facilities may offer early deployment opportunities for CAVs. Four scenarios were presented and discussed in smaller groups. The scenarios included a work zone incident, truck automation or platooning, CAVs allowed on freeways in mixed traffic, and transit and shared mobility using CAVs on dedicated managed lanes.

7 General Cross-Cutting Observations

As the field of road vehicle automation has advanced and the level of knowledge of the issues has grown over the past several years, the areas of emphasis within the Automated Vehicles Symposium have shifted. In this most recent meeting, several general observations are worth noting:

- There was increased recognition of the importance of treating the vehicles and the infrastructure as part of a combined road transportation system rather than being distinct from each other. This led to consideration of the likelihood that different locations will have their roadway infrastructure (traffic control devices) at different levels of readiness to support vehicle automation.
- More serious consideration has been given to the development of regulations to govern the testing and public operation of automated driving systems, including the relative roles of the federal and state governments and the approaches for achieving consistency among the different states. These issues for the federal system in the U.S. are reflected at the national and continental level respectively in Europe.
- Increasing attention was devoted to the trucking and transit applications as early deployment opportunities for the higher levels of automation, based on both economic and operational practicality considerations. Platooning of trucks was much more widely recognized and discussed than in the earlier meetings.
- There was a wide range of topics discussed associated with user interactions with highly automated vehicles, including interactions both internal and external to the vehicles. This extended to topics on vehicle automation for disabled travelers and the challenges of interacting with vulnerable road users.
- The discussions about legal and insurance issues advanced beyond identification of problems into discussions of potential solutions to those problems.
- There was a broader recognition of the vital importance of developing solutions to the safety assurance and cyber security challenges before the automated driving systems can be deployed.

- There was extensive discussion within sessions and during informal networking periods on what will be considered "safe enough" when certifying automated vehicle deployment. This is compounded by the challenge of not being able to test all use cases in the first place. There is a delicate balance between general increases in safety and driver convenience, along with efficiency of transportation, but with occasional unexplainable crashes and even fatalities that would not be expected with human drivers.

Part I
Public Sector Activities

SIP-adus: An Update on Japanese Initiatives for Automated Driving

Yoichi Sugimoto and Seigo Kuzumaki

Abstract This is a report on the latest SIP-adus activities. SIP-adus is a five-year research program on connected and automated driving led by the Japanese government that began in 2014. Beginning in 2016, the project prioritized five themes (Dynamic Map, human-machine interfaces (HMI), cyber security, pedestrian collision reduction, and next-generation transport). Large-scale field operational tests started in October 2017 around Tokyo area in order to integrate and evaluate achievements. The tests are open to global entities, and more than 20 entities have participated to date.

Keywords Automated driving · Automated vehicles · Connected vehicles
Dynamic map · Human factors · Field operational test · Cyber security
SIP-adus · Japan

1 Overview of the SIP-Adus Program

The Japanese government's Cross-Ministerial Strategic Innovation Promotion Program, called SIP, was started in 2014 as a five-year project. SIP aims to realize science, technology and innovation through basic research, application research and commercialization, with cross-ministerial cooperation. The project for automated driving systems for universal service (adus) was chosen by SIP as one of 11 research themes [1, 2].

The governmental framework for the promotion of connected and automated driving systems includes four relevant ministries and agencies under the leadership

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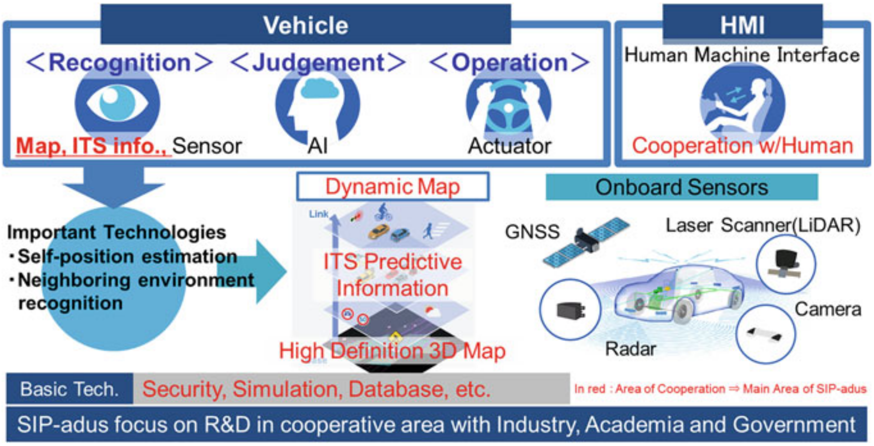


Fig. 1 Technologies for automated driving systems and SIP-adus focus areas

of the Cabinet Secretariat and the Cabinet Office. The responsibilities of the Cabinet Office are comprehensive planning and coordination function for R&D promotion on automated driving systems. Connected and automated driving systems, which provide benefits to our society, require collaborative efforts among government, industry and academia.

When starting SIP-adus, reducing the number of traffic fatalities was set as the goal with the highest priority. Automated driving systems are thought to have major potential for reducing traffic collisions. The second goal was to realize and spread automated driving systems as soon as possible. The third goal was to realize a next-generation urban transport system in time for the 2020 Tokyo Olympic and Paralympic Games.

For automated driving systems, it is necessary to develop various technologies, such as high performance on-board sensors like cameras or radars for recognition and artificial intelligence for judgment. Automakers are competing to develop these technologies now. In SIP-adus, it is challenging to cover all relevant themes with the limited resources available. Therefore, among all themes, the subjects in red shown in Fig. 1 were selected and classified as cooperative field technologies. Beginning in 2016, the project prioritized five themes (Dynamic Map, HMI, cyber security, pedestrian collision reduction and next generation transport). These activities are being conducted in cooperation with industry and academia.

2 Progress of SIP-Adus in the Focus Areas

In this chapter, progress in the five focus areas is reported.

2.1 Dynamic Map

Figure 2 shows a concept of Dynamic Map. Dynamic Map consists of a highly accurate 3D map and dynamic data. It is conceptually composed of four layers: static data, semi-static data, semi-dynamic data and dynamic data. This Dynamic Map database is thought to be useful not only for automated driving vehicles, but also for all other vehicles and drivers on the road.

As Dynamic Map data should be fresh, the ease with which data can be updated is important. Also, scalability, low cost and security are required. Since it is a large burden for auto makers and map suppliers to prepare their own maps independently, Dynamic Map was determined to be an area of collaborative interest, and Dynamic Map database is to be established with government and private sector cooperation.

In the future, almost all vehicles will be equipped with sensors, such as cameras and radars, and data communication modules. Probe data will help update map data, which will decrease the cost of Dynamic Map (Fig. 3).

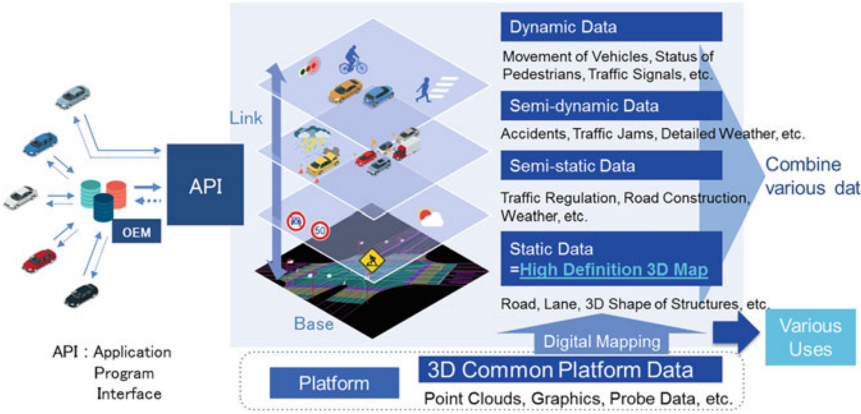


Fig. 2 The concept of dynamic map

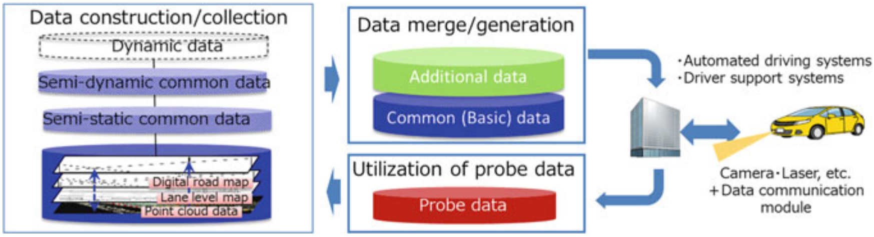


Fig. 3 The data flow of dynamic map

As the result of two years of the SIP activity, Dynamic Map Planning Co. Ltd (DMP) was established in 2016. Six map companies and nine automakers invested in the company.

DMP is now developing the methodologies of creating and maintaining a high-precision 3D map data for automated driving systems. It is also conducting a feasibility study on the business prospects of Dynamic Map data providers.

In June 2017, the planning phase was completed, and DMP became a business enterprise [3].

2.2 Cyber Security

Utilization of wireless communication such as Dynamic Map and vehicle-to-x (V2X) technology makes cyber security a critical issue.

In order to enhance cyber security performance, SIP-adus tries to elicit security requirements by building common models based on threat analysis. Validation/evaluation methodologies and criteria for vehicle level cyber security are targeted for development (Fig. 4).

2.3 Human Machine Interface

Regarding human machine interfaces, there are three important research themes to be studied.

The first is to investigate the effects of prior system information on drivers' behavior when using automated driving systems [4].

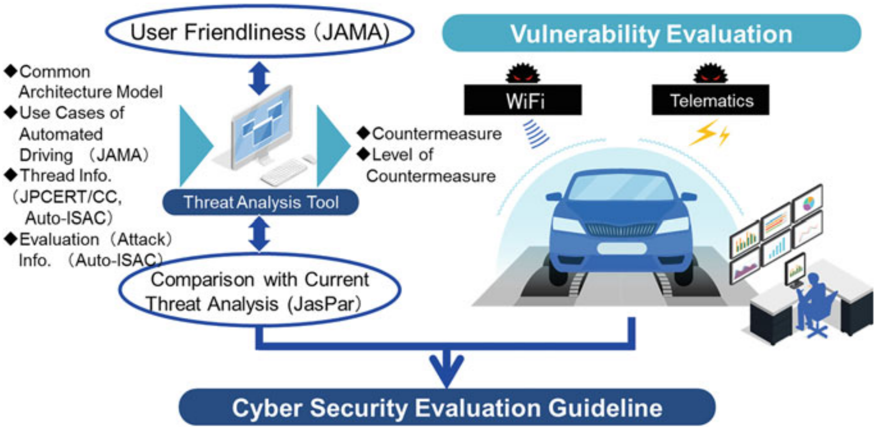


Fig. 4 The approach on cyber security

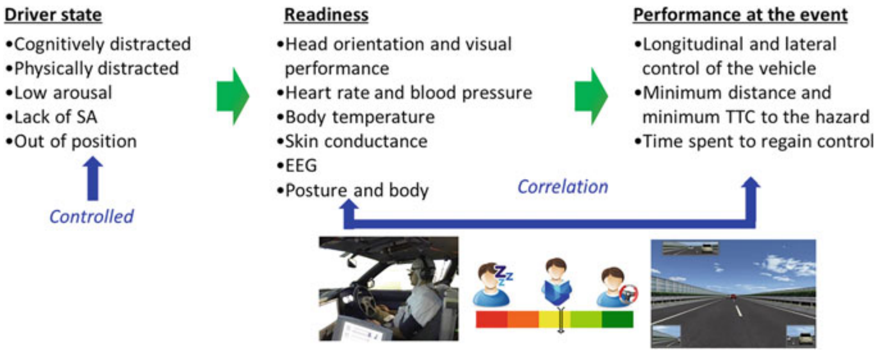


Fig. 5 HMI research

The second is to investigate the effects of a driver state on his/her behaviors when transitioning from automated driving to manual driving (Fig. 5) [5].

The third is to investigate effective ways to functionalize automated driving vehicles to communicate with other road users under various traffic scenarios [6].

2.4 *Pedestrian Collision Reduction*

Pedestrians and cyclists account for approximately half of traffic fatalities in Japan.

In order to realize a direct vehicle-to-pedestrian (V2P) communication system that can alert pedestrians or drivers in the appropriate situation and at the correct timing, the key technologies required for a pedestrian terminal, such as 700 MHz-band communication and high-precision positioning, are being developed [7].

A 79 GHz-band infrastructure radar for pedestrian detection at intersections is also under development (Fig. 6).

2.5 *Next Generation Transport*

For the realization of automated driving systems on general roads, it is crucial to have a system that helps vehicles recognize traffic signal information in real time.

The Public Transportation Priority System (PTPS) is one application that is effective with traffic signal control [8].

Other real-time traffic information, such as traffic congestion, bus locations and dynamic connection guidance, are useful for smooth and safe transportation. A traffic information database is to be developed based on Dynamic Map (Fig. 7) [9, 10].

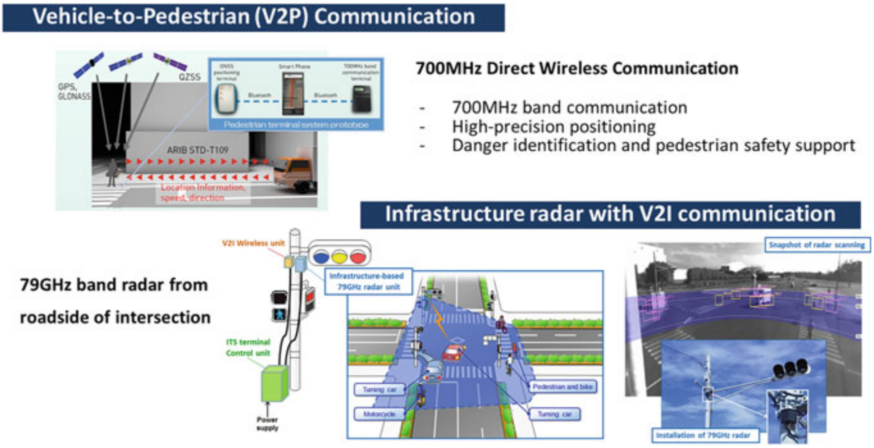


Fig. 6 Pedestrian collision reduction

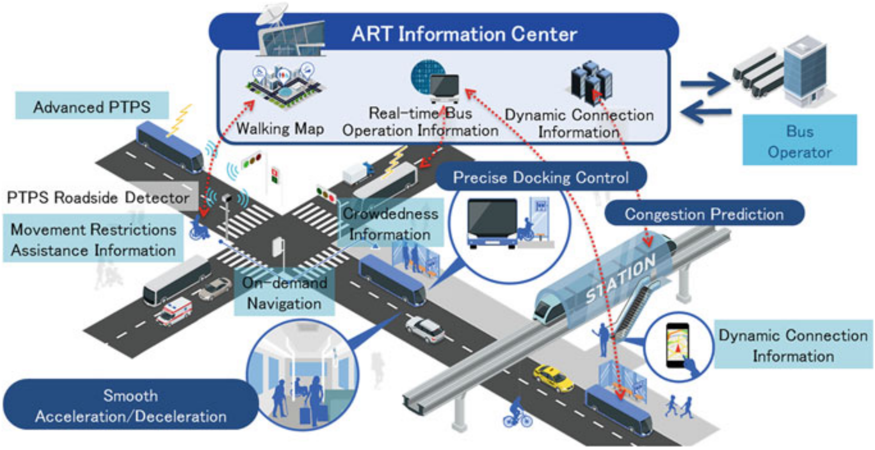


Fig. 7 Next generation transport

3 Outline of the Field Operational Tests (FOT)

Large-scale field operational tests began in Japan in October 2017. They will last until March 2019.

The main purpose of the FOT is the validation of automated driving system technologies under real environments on public roads.

Another purpose is to enhance international cooperation and harmonization. SIP-adus welcomes open discussions with every stakeholder from around the world. Currently, over 20 entities, including global automakers and suppliers, have joined (Fig. 8) [11].

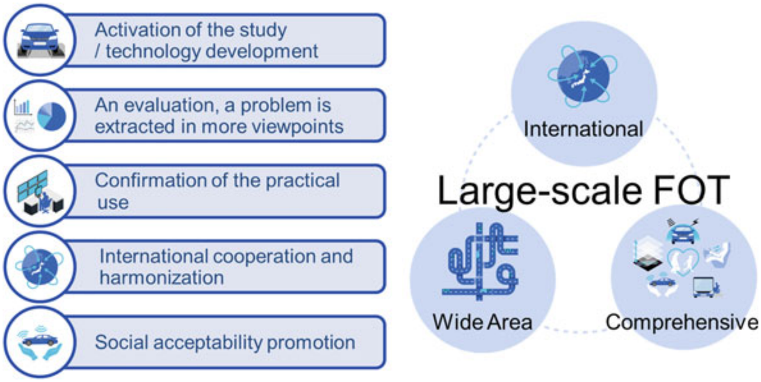
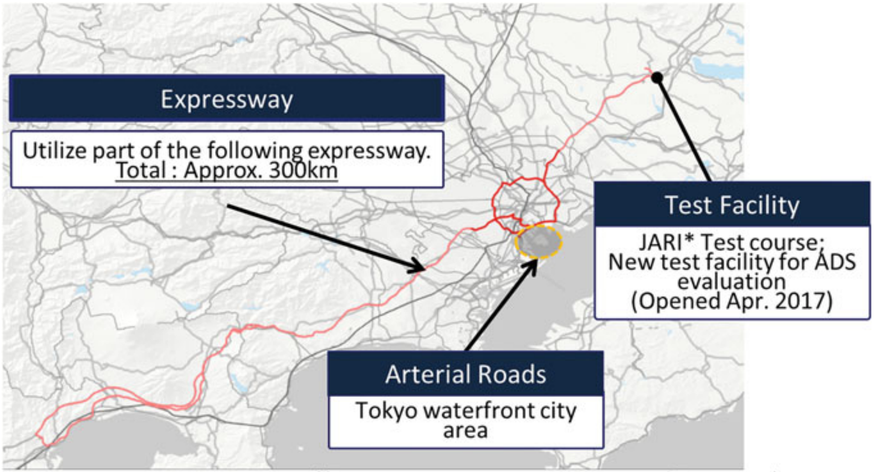


Fig. 8 Field operational tests by SIP-adus



(*JARI : Japan Automotive Research Institute)

Fig. 9 FOT test sites

3.1 Test Sites

The test sites shown in Fig. 9 are routes that total about 300 km, including part of the Metropolitan expressway, arterial roads in the Tokyo waterfront city area, and a newly developed test facility belonging to the Japan Automobile Research Institute.

While SIP-adus prepares these test fields, participants need to prepare test vehicles and test drivers.

3.2 Testing Activities in Focus Areas

3.2.1 Dynamic Map

SIP-adus provides the Dynamic Map data to the participants. The participants are expected to install this data in their own vehicles and evaluate it during use on actual public roads.

The objectives are to validate high-resolution map data, to validate data collection and distribution methods, and to verify the utility of semi-dynamic map information (Fig. 10) [12].

3.2.2 HMI

The main theme of HMI FOT is to collect and analyze driver status data, to define the status of drivers' readiness to take over driving, and to verify HMI methods and devices.

During this FOT, measurements, data collection and analyses of driver status under actual driving environments through continuous long drives are being conducted.

3.2.3 Cyber Security

Regarding cyber security, the objectives are to validate the evaluation method for attacks from outside a car and to verify the defense functions of automated driving vehicles.

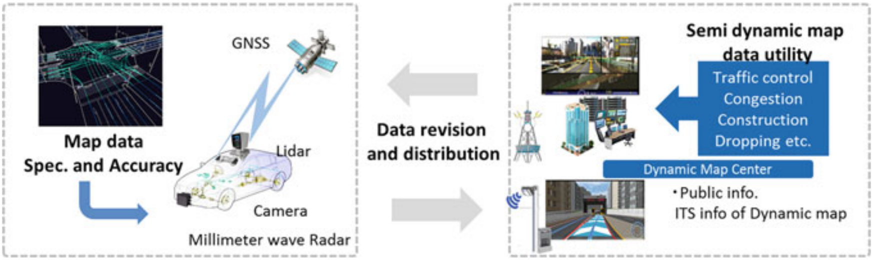


Fig. 10 Dynamic map validation in the FOT

4 International Cooperation and Harmonization

Since the 1880s, automobiles have changed our lives and provided multiple benefits to our society. But in the early stages of motorization, there was a great deal of confusion, and terrible traffic collisions occurred on the roads. In the 130 years of automobile history, a sophisticated automobile society has been established by creating traffic rules and regulations, and standardization made automobiles a commodity.

When automated driving vehicles enter the market, similar confusion and traffic collisions might occur. In order to maintain the safety and social order, established by our forerunners, harmonization and standardization should be promoted more vigorously. Automated and connected vehicles should be built on so-called common platforms.

SIP-adus set six themes as our main international collaborative themes, including Dynamic Map, connected vehicles, cyber security, impact assessments, human factors and next generation transport. Each theme is extremely complicated and requires harmonization. SIP holds an SIP-adus workshop every year to facilitate discussions on these themes, in addition to the EU-US-Japan trilateral framework of ITS cooperation and ISO.

5 Conclusion

SIP-adus is a five-year research program on connected and automated driving led by the Japanese government that was begun in 2014. Among relevant technical issues, cooperative field technologies were selected as the research themes of SIP-adus. In 2016, the project prioritized five themes (Dynamic Map, HMI, cyber security, pedestrian collision reduction and next generation transport). Large-scale field operational tests started in October 2017 to integrate and evaluate the achievements made so far. The tests are open to global entities and will provide opportunities to share meaningful results and to encourage mutual cooperation for harmonization on specifications and frameworks for connected and automated vehicle operations in the future.

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European Roadmaps, Programs, and Projects for Innovation in Connected and Automated Road Transport

Gereon Meyer

Abstract This chapter is summarizing the current initiatives in support of connected and automated driving taken by public authorities, academia and industrial stakeholders in Europe. It is covering the actions by the European Commission, such as the GEAR 2030 strategy, the C-ITS platform, the cooperation of automotive and telecom industries for connectivity, and the strategic transport research and innovation agenda (STRIA). At the same time, the roadmaps of European technology platforms and public private partnerships such as EPoSS, ERTRAC, ECSEL and EATA are explained. Also, an analysis of funding calls and projects for the Automated Road Transport (ART) topic of Horizon 2020 is given, and additional programs such as ICT, ECSEL, PENTA, and the Urban Innovative Actions are introduced. The results of a worldwide benchmark study are reported as well. Finally, the two Coordination and Support Actions forming the connectedautomateddriving.eu initiative, SCOUT and CARTRE are presented and their efforts to establish a comprehensive roadmap to accelerate innovation of connected and automated driving in Europe are summarized.

Keywords Europe · Connected and automated driving · Horizon 2020
GEAR-2013 · C-ITS · STRIA · 5G · EPoSS · ERTRAC · EATA
SCOUT · CARTRE

1 Introduction

In the 1990s, European vehicle manufacturers and automotive suppliers were among the pioneers to introduce advanced driver assistance systems like e.g. electronic stability control (ESC) after essential technologies had been developed within research and development programmes such as PROMETHEUS, heavily

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funded by European member states. Hence, ambitions are high to remain in the lead when it comes to the development, piloting and early deployment of connected and automated driving of SAE levels 3–5, despite many European countries are bound to the Vienna Convention. Thus, in the Amsterdam Declaration of 14 April 2016, European state leaders called for a shared strategy on automated and connected vehicles, and in a Letter of Intent signed by high level government representatives on 23 March 2017 in Rome, member states committed to jointly carry out testing and large-scale demonstrations of connected and automated driving. In parallel, the European Commission has launched a multitude of strategic initiatives and established research and innovation funding programs, acknowledging the roadmaps and recommendations by European Technology Platforms. The joint European strategy was discussed at the first European Conference on Connected and Automated Driving organized by the European Commission on 3–4 April 2017 in Brussels, and future research needs and roadmaps were compiled at an Interactive Symposium on Research and Innovation for Connected and Automated Driving in Europe, held on 19–20 April 2018 in Vienna.

2 European Union Policy Initiatives

The European Commission has established a number of policy initiatives to support an accelerated deployment of cooperative, connected and automated driving, recently.

2.1 Gear 2030

In view of the game-changing trends and challenges the automotive industry is facing, the Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (DG GROWTH) of the European Commission in October 2015 established a High Level Group on Automotive Industry (GEAR 2030). The group, which involved representatives of European Member States, industrial and societal stakeholders, made recommendations to reinforce the competitiveness of the European automotive value chain. Its members jointly edited roadmaps that set objectives, specify milestones and define the responsibilities. Discussing the impacts of the introduction of autonomous vehicles in their final report, [1] they note that EU governance would be needed to take the full benefit of large scale testing and research and financing programs both at the EU and at Member State level, and they are pointing to the need for data handling rule, coherent traffic and vehicle rules, and new approaches for vehicle type approval. According to GEAR 2030, the required connectivity needed to be provided in the vehicle and the infrastructure, and the socio-economic impacts had to be assessed.

2.2 C-ITS Deployment Platform

The interaction between road vehicles and infrastructure is the subject of Cooperative Intelligent Transport Systems (C-ITS). Such systems provide road users and traffic managers with the opportunity to exchange data and to apply those data for traffic flow coordination. Communication between vehicles, infrastructures and road users is particularly essential to ensure the safety of automated vehicles and their integration in the transport system. Cooperation, connectivity, and automation thus are technologies that work together in a synergetic way. In 2014, the Directorate-General Mobility and Transport (DG MOVE) of the European Commission launched a C-ITS Deployment Platform that includes national authorities, C-ITS stakeholders and the European Commission for a dialogue on the path towards interoperable deployment of C-ITS. Based on the work of the platform, the European Commission adopted a European Strategy on Cooperative Intelligent Transport Systems (C-ITS) [2]. The objective of that strategy is the EU-wide coordination of investments and regulatory frameworks to prepare for the availability of C-ITS services in 2019 and beyond. The C-ITS platform is strongly liked to the C-Roads platform which is gathering real-life deployment experiences from various sites in the European Member States [3]. Currently, the C-ITS platform is working on draft security and certificate policies for C-ITS to enable connected and automated driving.

2.3 Connectivity for Automated Driving

Safety concerns would limit the feasibility of higher level automated driving, particularly at SAE levels 3–5, to very few use cases of reduced complexity, if the environment perception of cars were based on in-vehicle sensors only. Vehicle-to-vehicle data communication, and even more, connectivity with sensor systems in the infrastructure and links to dynamic maps, artificial intelligence and big data analytics in the backend, could increase the capabilities of automated vehicles to understand complex traffic situation. They may even become a requirement for allowing the operation of self-driving cars e.g. in urban environments. This requires data links providing high bandwidths and low latencies, as they are offered by either (long range) 5G mobile communication or (short range) wireless internet. EU-Commissioner Guenter Oettinger (then in charge of the Digital Agenda) in 2015 launched a round table to bring together the automotive and telecom sectors for a closer cooperation and development of a roadmap on connected and automated driving [4]. As a result, the European Automotive Telecom Alliance (EATA) was formed.

2.4 Strategic Transport Research and Innovation

The research and innovation needs in connected and automated driving are covered in the roadmap “Connected and Automated Transport” of the Strategic Transport Research and Innovation Agenda (STRIA) that the Directorate-General Research and Innovation (DG RESEARCH) of the European Commission compiled in 2017 [5]. Like the other six STRIA reports, it was published as part of the European Commissions communication package “Europe on the Move” [6]. According to this roadmap, short-term research needs are seen in: Large-scale cross border demonstration, human factors, testing and validation procedures and in the assessment of socio-economic and environmental impacts of connected and automated driving. On the longer term, perception systems and artificial intelligence ensuring road safety, and infrastructures supporting the integration of connected and automated vehicles into the wider transport system will require additional research. Currently, the European Commission is setting up a governance structure for the implementation of the STRIA roadmaps. It involves EU institutions, Member States, local administrations and other relevant stakeholders. Since 2016, research and innovation projects have been funded in the framework of the Automated Road Transport (ART) section of the Transport Work Program.

3 European Stakeholder Positions and Roadmaps

European stakeholders from industry, academia and civil society are contributing significantly to the strategic discussions on research, innovation and deployment of connected and automated driving through a multitude of platforms. With the support by their members and an in close cooperation with associations such as European Council for Automotive Research (EUCAR), European Association of Automotive Suppliers (CLEPA), European Automotive Research Partners Association (EARPA), ERTICO—ITS Europe, and the Cities and Regions for Transport Innovation (POLIS), the European Technology Platforms ERTRAC and EPoSS, the Joint Undertaking ECSEL and the European Automotive-Telecom Alliance (EATA) recently have released roadmaps and strategic positions.

3.1 ERTRAC

The European Road Transport Research Advisory Council (ERTRAC) just recently published a new edition of its Automated Driving Roadmap that had originally been released in 2015 [7]. It summarizes the challenges of connected and automated driving in three categories: vehicles, systems and services, and society. For vehicles, in—vehicle technology enablers, as well as production and industrialization are listed as fields requiring further research. For systems and services, human factors, connectivity, digital and physical infrastructure, big data and artificial intelligence, new mobility services, shared economy, and business models are mentioned. For society, user awareness and societal acceptance and ethics, needs for policies, regulation and European harmonization, socio-economic assessment and sustainability, as well as safety validation and roadworthiness testing are considered. Recommendations are derived for the 2018–2020 calls for proposals of the Horizon 2020 work programs.

3.2 EPoSS

In its "European Roadmap Smart Systems for Automated Driving" the association of the European Technology Platform on Smart Systems Integration (EPoSS e.V.) is describing the goals and challenges as well as the state of the art of automated driving [8]. A particular focus is put on the enabling role of smart electronic systems and architectures. These include navigation systems for localisation and positioning, sensing and perception systems, sensor networks and fusion, vision systems for guidance and control as well as self-learning algorithms. The sensor suite of a highly automated vehicle comprises several smart systems such as high-end laser scanners creating a 3D surface map of the environment, as well as camera and radar sensors that complement each other by lateral and spatial resolution. The roadmap covers evolutionary and revolutionary development paths and related milestones. Action fields have been classified in the following categories: Technology inside car, infrastructure, big data, system integration and validation, system design, standardization, legal framework and awareness measures. For each of the action fields, the content and the timescale of actions in R&D, demonstration and industrialisation is indicated. Currently, this roadmap is being complemented by an EPoSS position paper that emphasizes the user centric perspective, a vision for connected and automated driving 2030, the links to robotics, safety and security issues of automated driving, and synergies between automation, electrification and shared mobility.

3.3 ECSEL

The Joint Undertaking Electronic Components and Systems for European Leadership (ECSEL) is a public-private partnership of the European Union, Member States and three associations, EPoSS e.V., AENEAS and ARTEMIS-IA, representing the actors from smart integrated systems, micro- and nano-electronics, and embedded or cyber-physical systems domain. In its recently published Joint Strategic Research Agenda, "Transport & Smart Mobility" is considered an important application field, and "Ensuring secure, connected, cooperative and automated mobility and transportation" is seen as a major challenge [9]. According to the roadmap a number of issues require further research, development and innovation, in particular environment recognition, localization, maps and positioning, control strategies, hardware and software platforms for control units for automated mobility and transportation (including also support for artificial intelligence), communication inside and outside the vehicle, testing and dependability, swarm data collection and continuous updating, predictive health monitoring for connected and automated mobility, functional safety and fail-operational architecture and functions (sensors, electronics, embedded software and system integration), as well as management of mixed automated and manual traffic. To enable the related functionalities, electronic components and systems (ECS) are considered to be key, e.g. interacting information systems for safe and secure connection between vehicles and between vehicles and infrastructure, intelligent on-board traffic management and navigation systems, energy harvesting sensor and actuator systems, multi-core/many-core-based architecture, AI-based systems, safe fallback vehicle sensing and actuation systems as well as methods and tools to virtually validate and approve connected, cooperative, automated vehicles. ECSEL recently launched the Lighthouse Initiative Mobility.E that shall increase the impact of research and innovation projects promoting collaboration and fostering a continuous dialogue with the ECS community and between the ECS community and technology users, decision-making bodies and society. It is supported by a Lighthouse Initiative Advisory Service" (LIASE) that shall develop, maintain and implement a dedicated Lighthouse Initiative Roadmap.

3.4 EATA

The European Automotive Telecom Alliance (EATA), an umbrella organization of companies and associations, recently presented a roadmap for the deployment of connected and automated driving functionalities [10]. According to that roadmap, the deployment shall happen in three steps. At first, highway chauffeur and high-density truck platooning shall be supported by the pre-deployment of hybrid communications, network slicing, and LTE broadcasting in five EU countries. Thereafter, also valet parking shall be added and cross border functionality be available on motorways, then building also on 5G radio and evaluation relative localization, and finally, automated driving shall be deployed and commercialized on authorized highways. Part of the planned activities are co-funded by the European Commission and some partners of EATA in the project "Connected Corridor for Driving Automation" (CONCORDA).

4 Programs and Projects

The European Union has funded research and innovation in the domain of automated driving for more than a decade. The EUREKA project “PROgraMme for a European Traffic of Highest Efficiency and Unprecedented Safety” (PROMETHEUS) which took place between 1987 and 1995 and received 749 million euros in funding from the EUREKA member states, already covered many of the issues of automated driving that sometimes are still of concern today [11]. Automated driving also was the subject of funding in the European Commission’s sixth and seventh research framework programs. In the current Horizon 2020 program, specific call sections of the transport work programs have been dedicated to “Automated Road Transport” (ART, for 2015/16) [12] and “Digitising and Transforming European Industry and Services: Automated Road Transport” (DT-ART, for 2018–20) [13] with an allocated funding budget of more than 200 million euros. A summary of call topics and budgets is shown in Table 1.

Additional European funding opportunities for the topic of connected and automated driving have been provided by the ECSEL Joint Undertaking and the EUREKA cluster PENTA on micro and nano electronics [14]. Recently, the Directorate-General Communications Networks, Content and Technology (DG CONNECT) of the European Commission also launched a call for proposals on the topic “ICT-18-2018: 5G for cooperative, connected and automated mobility” providing a total of 50 million euros for Innovation Actions [15].

All current and previously funded EU-funded research and innovation projects on connected and automated driving are summarized in Fig. 1, distinguishing four research fields: Networking and Challenges, Connectivity and Communication, Driver Assistance Systems and Highly Automated Urban Transport Systems.

Automated road transport is covered by the “Urban Mobility” theme of the Urban Innovative Actions that provide funding from the European Regional Development Fund (ERDF) for highly innovative technology deployment projects to municipalities in Europe. Shared automated vehicles were among the most prominent solutions presented by the 86 applications submitted to the second call for proposal [16]. Two of the selected projects will receive funding for such solutions, namely “Transforming Urban Planning Providing Autonomous Collective mobility” (TUPPAC) by the City of Albertslund in Denmark, and “Collaborative Mobility Management for Urban Trafic and Emissions reduction” (COMMUTE) by Toulouse Metropole [17].

Table 1 Automated road transport calls in the EU Horizon 2020 program

Call ID	Topic	Type[a]	Budget (million euros)
ART-02-2016	Automation pilots for passenger cars	IA	48
ART-04-2016	Safety and end-user acceptance aspects of road automation in the transition period	RIA	13
ART-05-2016	Road infrastructure to support the transition to automation and the coexistence of conventional and automated vehicles on the same network	RIA	
ART-06-2016	Coordination of activities in support of road automation	CSA	3
ART-01-2017	ICT infrastructure to enable the transition towards road transport automation	IA	50
ART-03-2017	Multi-Brand platooning in real traffic conditions	IA	
ART-07-2017	Full-scale demonstration of urban road transport automation	IA	
DT-ART-01-2018	Testing, validation and certification procedures for highly automated driving functions under various traffic scenarios based on pilot test data	RIA	6
DT-ART-02-2018	Support for networking activities and impact assessment for road automation	RIA/ CSA	6/3
DT-ART-03-2019	Human centred design for the new driver role in highly automated vehicles	RIA	8
DT-ART-04-2019	Developing and testing shared, connected and cooperative automated vehicle fleets in urban areas for the mobility of all	IA	30
DT-ART-05-2020	Efficient and safe connected and automated heavy-duty vehicles in real logistics operations	tba	50
DT-ART-06-2020	Large-scale, cross-border demonstration of highly automated driving functions for passenger cars	tba	

[a] *CSA* coordination and support action, *IA* innovation action, *RIA* research and innovation action

5 International Benchmark

In a recent study on behalf of the European Commission, the maturity of the transportation systems was assessed in six different countries—Brazil, China, India, Japan, South Korea, USA—in comparison to the EU. The study covered all transportation modes and had five focus areas including automation and connectivity. It also provided actions plans on how to overcome existing European barriers towards a single and innovative European Transport System based on best practices and lessons learned in the countries under study. In addition to the actions plans, the recommendations for international collaboration were made [18].

According to the results of the study, the degree of maturity automated and connected transport is about alike ("good") in Europe, the U.S. and Japan, whereas

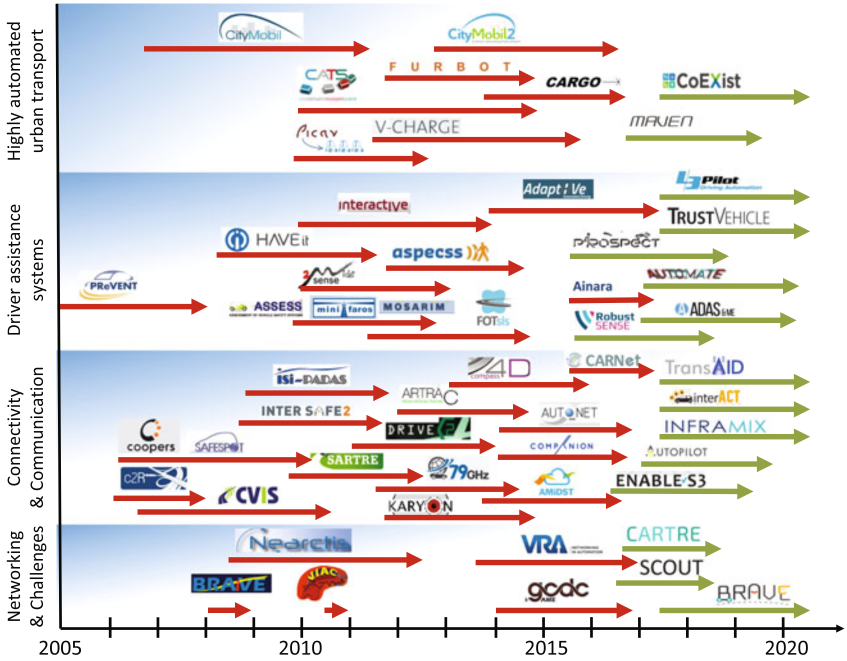

Fig. 1 EU-funded research and innovation projects in connected and automated driving

South Korea and China are just slightly lagging behind ("fair"). In terms of best practices, in particular the advanced regulatory framework for automated and self-driving cars in California and the comprehensive strategic initiative, SIP-ADUS, in Japan are highlighted. Moreover, the pilots of automated, electrified and shared vehicles in Singapore are considered to be trend-setting. Consequently, the study recommends for Europe (a) to establish the necessary regulations for testing and usage of automated driving in early anticipation of and parallel to the innovation process, (b) to integrate the three revolutions automation, electrification and mobility-as-a-service under one funding scheme, and (c) to combine research, piloting and deployment of connected and automated cars in one strategic program.

6 Comprehensive Roadmaps

The European Commission in 2016 launched two Coordination and Support Actions to assist the strategy development processes and the network building in the field of connected and automated driving: CARTRE, funded by DG RESEARCH, and SCOUT, funded by DG CONNECT. Both initiatives appear under one common umbrella and coordinate their work in terms of content development and dissemination, e.g. jointly supporting the European Commission in the preparation of the first European Conference on Connected and Automated Driving in 2017 and the Interactive Symposium on Research and Innovation for Connected and Automated Driving in Europe in 2018 [19]. In particular, both the CARTRE and SCOUT projects in close cooperation with ERTARC and EPoSS are working on strategic recommendations and comprehensive roadmaps for research and innovation in connected and automated driving in a mutually complementing way.

6.1 CARTRE

CARTRE focuses on identifying detailed research needs in a multitude of relevant technical and non-technical domains, including in-vehicle technology enablers, physical and digital infrastructure, connectivity, shared an automated mobility services, human factors, user acceptance and societal awareness, as well as socio-economic assessment. CARTRE therefore has established a wide network of working groups involving a multitude of relevant stakeholders.

6.2 SCOUT

SCOUT aims to establish a comprehensive and structured roadmap for connected and automated driving that reveals the interdependencies of technical and non-technical issues and identifies opportunities for accelerating the innovation process. The project therefore assesses use cases as well as societal goals and challenges, and formulates a vision for connected and automated driving. It also analyses the state of play in technologies and business models and identifies gaps and risks for the development and deployment of connected and automated driving.

The vision for connected and automated driving developed within the SCOUT project is putting the user into the center and tries to describe a desirable 2030 future scenario from his or her perspective. This has been achieved with the support of various stakeholders from e.g. city governments, vehicle manufacturers and telecommunication experts. The vision combines a number of solutions for connected and automated driving spanning a geographical sphere starting from cities over suburban, rural and interurban environments towards international areas. The suggested solutions such as robot taxi, universally designed vehicles and services, logistic hubs as well as connected traffic systems have been categorized into four areas of interest, namely mobility as a service, passenger transport, goods delivery and infrastructure. It turns out, that the essence of that vision consists in level 4 and 5 automated driving in different use cases. The technical challenges are very similar, though, and may be solved by smart systems that combine sensing with connectivity and intelligent decision-making. However, as such most advanced automated or self-driving functionalities have not yet reached full maturity, depend on a complex interplay of technical and non-technical issues, and are not yet allowed in most places, the process of roadmap development is particularly challenging.

The SCOUT consortium decided to apply the five-layers model that already was found to be appropriate for a description of the state of the art [20] to also grasp the complexity of the action plan to be established. According to that model, besides the technical layer as a basis for connected and automated driving functions, further layers describe the relevant non-technical issues, i.e. human factors, economics, legal, and societal aspects. The layers are strongly interlinked and they each are covering three interrelated topics, the driver (or passenger), the vehicle and the environment.

At two public workshop with the involvement of dedicated experts for all the five layers, actions were identified for each layer, linked to actions in other layers, and aligned on the time scale. It turns out that technical and non-technical challenges are highly related to each other with one action requiring the outcome of another one before it can start. The many inter-dependencies are creating a kind of Gordian knot indicating that the development and deployment of level 4 and 5 connected and automated driving may be heavily delayed if it is not comprehensively coordinated—a typical feature of complex innovation processes that touch a multitude of technical and nontechnical dimensions.

However, as can be seen from the simplified structure of the 5-layer roadmap of connected and automated driving (Fig. 2), solutions are possible and the innovation process is accelerated if roadblocks are anticipated and agile shortcuts are taken.

7 Conclusions and Outlook

In view of the legacy of innovation in technologies for connected and automated driving in Europe, and acknowledging the arising global competition in this domain, public authorities, academia and private stakeholders have launched a number of strategic initiatives: The European Technology Platforms ERTRAC and EPoSS have compiled research needs, the European Commission has allocated substantial budgets, and networks like the CARTRE and SCOUT project created added benefits by analyzing programs, bundling projects and giving advise for future directions. The various actions are still quite diverse and at risk to loose momentum if not comprehensively coordinated mutually and with the actions by European member states. One issue is the complexity of the paradigm shift connected and automated driving is representing due to the strong interplay of technical and non-technical factors. As shown in this paper, a more agile innovation process may be a way out. If well coordinated with all stakeholders, critical mass could be generated, and the multitude of diverse competencies available in Europe could be leveraged. In the near future, there will be a number of opportunities for this, ranging from the implementation process of the STRIA roadmap on connected and automated driving with the involvement of Member States, via potential new public-private partnerships under the upcoming Horizon Europe framework

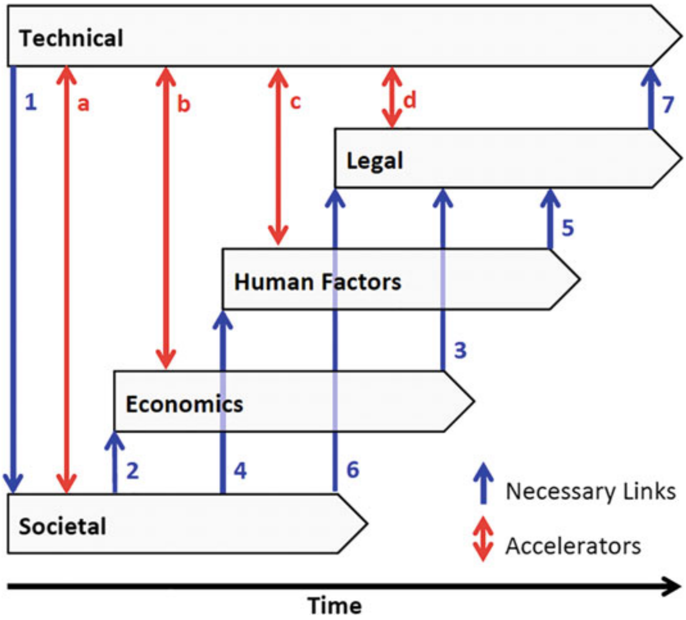

Fig. 2 Simplified structure of 5-layer roadmap for the highly interlinked innovation process in connected and automated driving. Delays are caused by sequences of actions on different layers that are determined by necessary links: (1) invention—e.g. a new robotic driving feature, (2) customer demand—e.g. readiness to pay more for the feature, (3) business model—e.g. sharing concept to operate the car and generate revenues, (4) user needs—e.g. requirements by other road users, (5) product design—e.g. new functionalities for communication with pedestrian, (6) norm—e.g. expected safety level of automated road transport, (7) regulation—e.g. approval for operation of new vehicle. The process may be accelerated by creating agile short cuts: (a) demonstration—e.g. automated driving pilots allowing the public to experience the pros and cons, (b) sandboxes—e.g. hackathons to develop new digital financing schemes, (c) co-creation, e.g. sessions applying universal design rules, and (d) living labs e.g. experimental legislation and standardization

program of the European Commission, to the game-changing "missions" the European Union intents to promote. Hence, there is a unique chance that Europe will drive forward disruptive innovation in connected and automated road transport as one of the main levers of the imminent transformation of mobility towards higher integration across the modes, better sustainability and greater societal benefit. This is well in line with the ambitions objectives expressed in a recent communication of the European commission [21].

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Drive Sweden: An Update on Swedish Automation Activities

Jan Hellåker, Jesper Gunnarson and Philip King

Abstract Drive Sweden is a government-sponsored cross-collaboration platform aiming to design and pilot the *future transportation system, based on connected, automated and shared vehicles*. Drive Sweden works as a unifying force between a range of stakeholders, and is complementing industry investments with discretionary use of government funding. The paper describes the overall effort within the Drive Sweden program, and goes into some detail about one of the sub-projects; the AD Aware Traffic Control project which was one of the last year's most important accomplishments. It was designed to provide a centralized traffic control function that facilitated the exchange of data from OEM's and third-party suppliers of traffic/weather information to aid the management of self-driving vehicles.

Keywords Autonomous cars · Autonomous shuttles · User acceptance
Cloud services

1 Drive Sweden: A Strategic Innovation Program

A few years ago, the Swedish government established a new instrument for addressing complex areas with huge potential to come up with sustainable solutions to challenges in our society, but requiring close cooperation among several stakeholders to get there. To date, seventeen such *Strategic Innovation Programs* (*SIP*) have been established, each with an expected duration of 12 years and with a considerable government co-funding behind it.

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Drive Sweden was established in 2015, when a proposal backed by 22 partners was approved by Vinnova, the Swedish Innovation Agency. Vinnova runs the Strategic Innovation Programs jointly with its sister agencies, FORMAS and the Swedish Energy Agency. By 2017 the Drive Sweden partnership has grown to 70+ partners including government agencies, industry and academia. Given its population, Sweden is home to an impressive range of vehicle manufacturers who obviously all play key roles in the program. However, having a national systems-perspective of how we want to shape tomorrow's mobility services is really the most important aspect of the program, and contributions from e.g. cities, the ICT industry, suppliers, service providers and small start-up companies are all equally important.

The ultimate Drive Sweden vision for our future mobility can be summarized as; future personal transportation should be based on a comprehensive Mobility-as-a-Service model, providing nationwide roaming and fully integrated ticketing, and in turn based on travelling with connected, shared and—increasingly—self-driving vehicles.

1.1 Swedish OEM Activities in Automation

In the end however, personal transportation comes down to using a vehicle, and here is an update on the most interesting and current activities among the OEMs based in Sweden, in relation to our future mobility with a focus on the connected, automated and shared components.

1.1.1 Volvo Cars

Volvo Cars' *DriveMe* program is an ambitious effort to expose 'normal' users to self-driving cars to gain knowledge of how they would like them to work. The program has been on-going since 2013, and in the end of 2017 the first regular commuter families were given access to their vehicles. When the program finishes in around 2020, up to 100 users will have had significant time to experience up to SAE Level 4 automation with no safety driver on-board, but with plenty of data recording equipment gathering data for extensive evaluations. The tests where automation features are allowed to be engaged, are taking place on 50 km of selected public roads around Gothenburg (Fig. 1).

1.1.2 Volvo Group

Activities around truck platooning have continued after the European Truck Platooning Challenge, and in early 2017 Scania and Volvo launched the first multi-brand platooning project in which a commercial carrier will test longitudinal

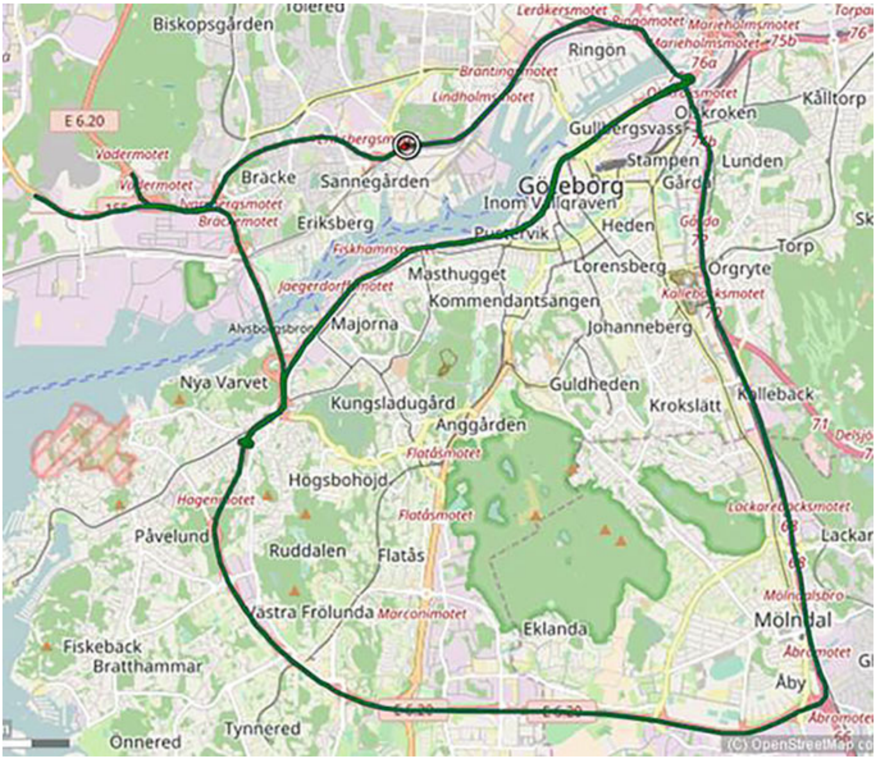

Fig. 1. The selected routes for drive me around the city of Gothenburg, Sweden

control between the two different brands in live traffic. Volvo has also accelerated its efforts on automation in confined areas, such as in mining applications. Also during 2017, a first prototype of an automated refuse truck was presented. In this use-case the truck operator walks behind the truck, handles the bins while the truck automatically follows behind him in a normal suburban setting.

1.1.3 Scania

Scania is pursuing similar activities as its national competitor in platooning and confined area applications, but has also stepped up its efforts on automating full-size city buses. As part of a contract with two Singaporean government agencies, Scania is developing a concept in which four trucks can be operated by one single driver in the first truck only. This has been successfully demonstrated on closed test tracks during the year.

1.1.4 Einride

Einride is a start-up company aiming to disrupt the freight market by a new product, the *T-pod,* which is a cab-less, fully electrified vehicle that will carry freight on public freeways, primarily overnight. The vehicle will be fully autonomous while on freeways, but centrally monitored with operators taking over remotely around loading docks.

1.1.5 Lynk & Co

Lynk & Co is a new brand within the Geely family, and essentially a sister brand to Volvo Cars. Their first car, the '01', was commercially launched in 2017 and offers in-vehicle, and back-end support for features such as sharing the vehicle with non-owners.

1.1.6 Nevs

NEVS, a company reborn after the SAAB bankruptcy, has shown an interesting concept vehicle and signed several cooperation agreements to become a mobility provider to regions and other primarily clients in China.

1.2 AD Aware Traffic Control—an Application on the Drive Sweden Innovation Cloud

Future mobility services will be dependent on access to data, not only from vehicles like the ones described above but also from other areas of the transportation system. One of the single biggest investments made so far by Drive Sweden has been to create an open innovation data laboratory, or the Drive Sweden Innovation Cloud. One of the first applications to be designed for this environment was Autonomous Driving (AD) Aware Traffic Control, which was developed in a project running between August 2016 and July 2017 [1].

1.2.1 AD Aware Traffic Control—Project Description

The Volvo Cars DriveMe project was the foundation for this project. In DriveMe the vehicles are capable of Level 4 automation, but if the vehicle cannot manage the situation it will attempt to make a controlled handover to the driver, if this is not possible then the car will perform a safe stop operation. This procedure should not be confused with Level 3 automation, where the system hands over responsibility more or less momentarily, and will not bring the vehicle to a safe stop. Autonomous Driving (AD) is allowed on a carefully mapped set of road segments but not under severe weather or extreme traffic conditions. When the vehicle is in AD Level 4 mode Volvo Cars takes the responsibility for the vehicles operation. This means that Volvo Cars must be able to execute that responsibility and allow, or revoke, AD driving in real time. We foresee that other OEMs and fleet owners will have the same needs in the future. We also foresee that different vehicle models will have different capabilities that will grow over time therefore enabling AD driving to be undertaken in a wider range of situations. Regulation on data protection and privacy must be fulfilled and privacy by design is preferred.

The OEM cloud, in our case an AD enabled instance of the (commercially operational) Volvo Cars' Sensus Cloud, handles the communication to and from the vehicles. The route, position and other data is communicated to the OEM cloud. As the OEM is the only party that knows about the vehicles, their AD capability, and takes the responsibility for these vehicles when in AD mode, its natural that the OEM cloud also contains the functionality to allow or revoke AD driving possibilities.

With the insight that many OEMs will have the same need for traffic and weather data we introduced the Central Traffic Control (CTC) Cloud, residing within the Drive Sweden Innovation Cloud environment. The CTC Cloud is assumed to be a Public or a Public Private Partnership instance that can serve any number of OEM clouds by aggregating all data of interest.

Within the CTC there is a Traffic Controller that monitors the traffic, weather, road situation (on the different certified roads) with automated support that can trigger alerts to the OEM clouds if there is an event that could affect AD driving. The data exchange between the CTC cloud and OEM clouds utilizes a Publish/subscribe and Request/response mechanism and uses DATEX II with some extensions for AD use cases suggested by the project.

The first service is *Transfer of certified road segments map data* from the OEM to the CTC. The OEM mapping of the certified road, in our case the ring motorway around Gothenburg has more than 1000 segments. This has been reduced to 17 segments to reduce complexity. Map data is transferred (DATEX II) to the CTC, then map matches these segments to the CTC map and a manual feedback is sent to the OEM to check the validity.

The next service is *Transfer of road segment approval status* from the OEM to the CTC. This allows both traffic controllers to have the same situation awareness. This is to say that both parties know the status of each certified road segment, whether AD driving is currently allowed or not.

CTC advice on AD driving based on situation. The CTC reads the DATEX II message stream from Trafikverket (Swedish Road Administrations Safety related traffic information service) and map matches the events. Road conditions like: Lane closures, Road blockage, Construction sites, Faulty Signs on a certified road segment will trigger an advice message to the OEM AD traffic control that will then enable them to take a decision to allow or revoke AD driving on that segment and send this data to the vehicle. The road segment approval status is sent back to the CTC.

CTC road weather service (situation and forecast). The CTC aggregates weather data and based on thresholds will trigger an advice message to the OEM AD traffic control that will allow them to take an action as in the case above.

Extreme weather conditions can be:

- Low visibility on a specific section of certified road
- Extreme precipitation on a specific section of certified road
- Snow on a specific section of certified road
- Low lane marking visibility on a specific section of certified road
- Low object visibility on a specific section of certified road
- Low friction on a specific section of certified road
- Strong winds on a specific section of certified road
- Aquaplaning risk on a specific section of certified road.

OEM vehicle sensor data to CTC. Volvo Cars' Sensus Cloud can today share (aggregated) road friction information and amber hazard blinker information. In the project today, we get this data and road works warning from 12 TMA blocking trucks in Gothenburg from the Nordic Way Interchange Node1. This can be developed further with more sensor data from connected vehicles to improve the situation awareness.

In order to protect privacy, the OEM AD control sends the *Density (flow) of AD vehicles in AD mode* on all road segments to the CTC rather than the actual car information. This can only be simulated now but is regarded as a good function for the future public traffic management of mixed traffic.

And finally, in order to protect privacy, the OEM AD control does not expose the position of any individual AD vehicle that has made a safe stop. However, *Safe stop alert* to CTC will be based on aggregated data (like 3 safe stops within 3 km and 3 min).

1.2.2 AD Aware Traffic Control—Main Findings

Community/Society:

- The CTC creates a Collaborative Situational Awareness that is beneficial for all connected stakeholders, many of which both contribute to and use the information in the CTC. By using a collaborative approach to ITS it is possible to collect and fuse information that contributes to a safer traffic situation.
- The need for data privacy (cf. GDPR) makes it necessary to have several levels of traffic control. Vehicle and personal information are aggregated and filtered when communicated with CTC from OEM Traffic Control to protect the privacy of individuals.

- This project, together with Nordic Way, points out the way to evolve traffic management by aggregating and sharing sensor data from connected vehicles. The situation awareness will reach new levels of detail. The other important feature is that traffic management now, via the OEM cloud, can reach out to the vehicles. In this project, we focus on AD vehicles, but the principles can be used for all connected vehicles.

Environmental:

- Traffic Flow Information—The project has demonstrated the exchange of traffic flow information between autonomous cars and the central traffic cloud. All connected vehicles can contribute with data that enhances the possibility of proactive traffic management that can reduce congestion and also limit the environmental impact of AD Aware Traffic Control traffic. When the vehicles are autonomous the effect of a proactive traffic management could potentially be even more positive.

Business:

- The CTC could act as a data broker, potentially creating a marketplace for information from autonomous and connected vehicles.
- Public-Private partnership will be the most likely business set up.

Organizational:

- A high-level goal of the project was to suggest a roles and responsibilities model for relevant actors—i.e. driver, OEM, national/regional traffic authorities, etc. Even though the different actors in the project agree on the benefit from having a CTC that provides collaborative situational awareness, the responsibility for operating the CTC remains to be further investigated.
- Other organizational issues still to be investigated are relations between the CTC and other commercial integration platforms, relations between the CTC and traffic management systems on regional, national and international levels, etc.
- The CTC is a central node but it must be possible to arrange a “federated network” of CTC´s that can interact and cover adjacent areas (cities or nations) or even the same area (public and private roads).

Technical:

- The project has shown that on a technical level it is possible to build a cloud based central traffic control for autonomous and connected vehicles using existing and open standards (i.e. DATEX II, Open Geospatial Consortium (OGC), OpenLR, AMQP). However, in order to communicate autonomous driving advice (allowed/not allowed) within DATEX II, the standard needs to be extended. One delivery from this project is the start of a proposal that can be submitted to the DATEX II standardization board (CEN TC 278).
- The Drive Sweden Innovation cloud proved to be a good environment to execute the project in.

1.3 Pilots to Involve End-Users

User acceptance of self-driving vehicles will be critical for consumer acceptance. Hence Drive Sweden is preparing for two commercial pilots in which literally anyone can experience traveling in a self-driving shuttle travelling in mixed traffic, to get them acquainted to the new technology.

Two such projects will be launched, one in the Stockholm area and one in Gothenburg. In both these pilots, substantial focus will be put on researching user feedback.

1.3.1 Stockholm Pilot

The Stockholm pilot will initially run in Kista, outside of Stockholm where two shuttles will be in commercial operation along an approximately 1 km long city street from a subway station to the main hotel in the area. This pilot will start in January of 2018 and continue for six months. Thereafter it will be moved, and expanded by more vehicles, to the suburb of Barkarby, serving as a first/last mile connection from a very dense new development to public transportation hubs in the neighborhood (Fig. 2).

Fig. 2. One of the shuttles that will be used in the Kista pilot

1.3.2 Gothenburg Pilot

The Gothenburg pilot will start in late Q2, 2018, when two Navya vehicles will serve an intra-campus route at the Chalmers University of Technology during six weeks. Later in 2018, the two vehicles will be put in operation in a remote parking shuttle application at Lindholmen.

2 Conclusions

The projects described here highlights the potential to solve many of today's societal transportation problems by leveraging connected, automated and shared vehicles, in combination with a smart, digital infrastructure. However, at the same time, our experiences so far emphasize the need for continued close collaboration between various stakeholders in order to drive this development further.

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Part II
Human Factors and Challenges

Research to Examine Behavioral Responses to Automated Vehicles

Johanna Zmud, Felipe Dias, Patricia Lavieri, Chandra Bhat, Ram Pendyala, Yoram Shiftan, Maren Outwater and Barbara Lenz

Abstract This chapter provides a discussion of the important research topics for understanding behavioral responses to highly automated vehicles (AVs) as discussed at a breakout session at the Automated Vehicle Symposium (AVS) 2018. The session, and thus this chapter, highlights the need for valid behavioral data on which to base assumptions, models, forecasts, and impacts to inform AV adoption behaviors, the pathways of AV ownership and use, and the potential impact of AVs on human activity-travel behaviors and longer-term location choices.

Keywords Automated vehicles · Land use · Travel behavior · Auto ownership Policy · Attitudes and Perceptions · Technology

1 Introduction

Automated vehicles (AV) are potentially transformative technologies with impacts, costs, and benefits to the transportation system that are highly uncertain. AV technology takes some, and eventually all, of the responsibility for vehicle

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The original version of this chapter was revised: Misspelt co-author name has been changed. The correction to this chapter is available at https://doi.org/10.1007/978-3-319-94896-6_22

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operation out of the hands of a human driver. Since most traffic accidents are caused by human errors, the potential safety benefits are compelling. Other potential benefits relate to congestion mitigation and air pollution reduction. The expected deployment path and timing for such vehicles is uncertain. AVs may deploy as privately owned vehicles and/or mobility fleets. They may deploy within the next year or the next decade. The timing depends less on technology development and more on policy and market demand.

As highly automated AVs are not yet operating freely on public roads (other than as pilot tests), it is important to examine creative approaches for assessing their potential impacts on the transportation system. This chapter identifies research needs and research approaches for gaining deep insight on behavioral responses to AVs in three priority areas: (1) vehicle ownership and use choices, (2) land use choices, where people choose to live and work, and (3) activity and travel choices, what people do, how often, how they get there.

Transport and land use impacts will vary significantly depending on extent to which AVs are used as privately owned vehicles, sequential ride-hailing fleets, and/or pooled ride-sharing fleets. Policy makers, public road operators, and transportation service providers need empirical data (not modeled simulations) on potential behavioral responses. However, capturing accurate answers to what people might do in future is tricky; preferences change as policies/society/technology mature. Research participants today are in a vastly different situation than what people will be in years from now when the technology is widespread. For example, asking an 18 year-old today about his/her likely use of AVs is wildly different from asking a future 18 year-old who has grown up with highly automated technologies available since they were born.

Perhaps the best researchers can do in the short-term is to track and monitor. We need to better understand current trends in vehicle ownership and vehicle usage, and through such insights better forecast likely impacts. However, such understanding has to be based on empirically derived data, not based upon arbitrary

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assumptions and the running of mechanical simulations. True insight will be achieved by research focused on better understanding behavior through attitudes, lifestyle issues, adoption behavior, situational influences and foundational activity-travel pattern choices. Ultimately, researchers need to begin to answer the question: How might behavioral trends change when the driver is removed?

The remainder of this chapter attempts to offer a research agenda to gain insights on behavioral implications of automated vehicles. The chapter is organized recognizing the differing temporal scales of various behavioral choice dimensions. Longer term location choices are addressed first, more medium-term mobility choices (vehicle ownership) are addressed second, and shorter term mobility choices (day-to-day and within-day activity-travel patterns) are addressed in the final section of the chapter. For each choice dimension, the discussion identifies key research questions in an attempt to craft a research roadmap, together with the data that need to be collected to answer the research questions.

2 The Potential Implications of AVs on Longer Term Location Choices

2.1 The Linkage Between: Transportation and Land-Use

There is a vast body of literature and real-world evidence about the linkages between transportation and land use. Historically, improvements in mobility and accessibility made possible by the advent of faster and more efficient modes of transportation facilitated the spreading out of urban populations resulting in what is commonly termed “sprawl”. Investments in transportation infrastructure that increased transportation capacity, and consequently reduced travel times (or more broadly, the disutility of travel), has largely been met with an increasing tendency for low density land use development with both population and employment moving out of central cities and into suburban locations where land is less expensive and more plentiful.

Despite such a seemingly strong correlation between transportation accessibility and land use choices, the true processes that drive longer term location choices may be more complex. In particular, residential and work location choices may be driven at least to a significant degree by lifecycle stage of households and individuals that come with varied motivations in different stages of life. In the early stages of adulthood, young adults may choose to live in urban centers and enjoy all that higher density urban lifestyles have to offer. As they advance into more mature stages of adulthood, the desire to live in neighborhoods with excellent schools, very low crime, and larger homes with backyards at affordable prices naturally leads to a move into the suburbs where such residential housing stock is typically available.

In addition, there is considerable heterogeneity, both observed and unobserved, in residential and work location choices. As noted above, there are a number of observed socio-economic and demographic characteristics, built environment attributes, and school and crime statistics that drive residential location choices. However, there may also be unobserved attributes that contribute to heterogeneity in residential location choices in the population. Different individuals may have varying lifestyle preferences, mobility proclivities, and attitudes (say, towards the environment). These attributes are rarely, if ever, measured in typical travel surveys and, even if they are collected, they are virtually never included in travel models. However, these personality traits and preferences are likely to influence residential location choice with those preferring higher density urban environments with many opportunities for activity engagement accessible by non-motorized modes of transportation and public transit more likely to choose residential location choices that are consistent with their preferences. This phenomenon, often referred to as "residential self-selection", has been shown to be significant, thus contributing to unobserved heterogeneity. In this context, it should be noted that attitudes and preferences may change over time (just as lifecycle variables change over time). The dynamics in these unobserved traits may further contribute to complex patterns of residential location choice depicted by households as they move through the life course.

2.2 How Will Location Choices Evolve in an Automated Mobility Future?

It is widely recognized that the advent of automated vehicles (AVs) will affect accessibility, making it less onerous to travel between places. It is also known, as noted previously, that accessibility affects location choices. However, the main question is whether the changes brought about by AVs will be structural (highly disruptive) in nature, or whether they will merely magnify/reduce effects that have already been observed over the past several decades? A non-structural change may simply lead to a modest increase or decrease in the rate of sprawl, for example, while a structural change may either dramatically increase the rate of sprawl or kill the suburbs and promote significant densification in urban centers. It is necessary to understand the relative magnitude of the effects of these technologies in comparison to effects engendered by the many other factors that are known to affect residential location choice (e.g., lifecycle, life goals, lifestyle preferences, school quality, neighborhood crime, and housing stock and prices).

There are two potentially conflicting forces at play, when it comes to understanding and estimating the impact of AVs on location choices in general and residential choice in particular. The improved accessibility and ability to multitask afforded by AVs are likely to induce further sprawl due to the decrease in the disutility of travel. However, at the same time, densification may occur as well because of changes in the urban landscape; for example, parking would no longer be an issue in dense areas, either because households could shift from a paradigm of private vehicle ownership to one of using shared mobility-on-demand services, or simply because of the ability to send the car to park itself at any suitable and available location without consideration of difficulties related to access/egress. These conflicting forces are in turn closely intertwined with the vehicle ownership choices that households will make in an automated mobility future, further complicating the ability to accurately assess the relative strengths of the conflicting forces at play. In the absence of a solid understanding of these phenomena, it is possible that the net effect will be one of further sprawl or densification, or the net effect will largely be zero with both of the phenomena constituting equal and opposite forces.

Historically, as technology has made it possible to travel and communicate across greater distances with increasing levels of efficiency, development patterns have shown a clear tendency for sprawl. However, the advent of AVs (and shared automated mobility-on-demand services) may be so disruptive that patterns of development and mobility choices may see dramatic changes in the future. People may choose to reside in higher density urban environments to take advantage of automated vehicle mobility-on-demand services without the need for owning and maintaining personal vehicles and other infrastructure (e.g., residential parking spaces) associated with personal car ownership. The cost of using such mobility-on-demand services may motivate households to choose higher density living environments where distances to access a variety of destination opportunities would be smaller.

There are other constraints that may also prevent a dramatic increase in sprawl due to automated vehicle entry in the marketplace. For example, it is expensive for jurisdictions to provide services (emergency services, utility services, and recreational facilities) in far-flung sparsely populated areas. In an effort to remain within a certain travel time shed of such facilities and opportunities, households may avoid spreading out further even though automated vehicle travel would undoubtedly be significantly less onerous than traveling in a manually driven vehicle. In addition, access to healthcare facilities will continue to be an important criterion for residential location choice, particularly with an aging population in many countries of the world. Similar desires to have access to good schools and institutions of higher education, eating places, and other amenities may keep sprawl in check.

There are clearly a number of factors affecting residential location choice that are not yet fully understood in the context of automated vehicles. In addition, there are complex interactions that need to be taken into account to more accurately assess location choice impacts of automated vehicles. One of the key parameters that affects mobility and location choices is the value of time. How will value of travel time change with the advent of automated vehicles? Which segments of the population are truly eager and looking forward to using their travel time more productively? How large (or small) are these market segments? How does the reduction in travel time disutility engendered by automated vehicle usage vary across population segments? How important is the value of travel time, in comparison to other key factors, in choosing residential location? Would the changes brought about by AVs in the value of time be significantly stronger than other changes and technologies (currently in market) that allow travelers to be more productive, mainly via the use of cell phones and in-vehicle infotainment systems?

Is the value of travel time in an automated vehicle similar to that for a good train service that allows travelers to use time productively? And is the ride in an AV convenient enough to work efficiently? To what extent can people really work or engage in other activities in moving vehicles, given concerns about motion sickness, bumps and ruts in the roadway surface, and concerns about technology malfunctions?

As with any significant new technology, questions remain about the extent to which people would trust AVs, and the implications of trust for location and mobility choices. For example, would parents feel comfortable to send their kids alone in an AV? If yes, then it is plausible for households to live farther away in more sprawled settings because chauffeuring children to and from school is no longer a major constraint. However, if parents do not have such trust in the technology, then households may be more restricted in their location choices as they strive to remain within a reasonable travel time and distance of good schools and recreational and after-school activities for their children.

There are other land use impacts that remain largely unknown in the context of an AV future. Recent trends have seen many older households move into the urban centers to access opportunities more easily. Would the introduction of AVs slow down this trend, with elderly households comfortable residing in suburbs well past retirement age because AVs can easily transport them to and from activity destinations? Also, how will changes in the need for parking affect land use decisions? If vast expanses of central city land devoted to parking can be reclaimed for housing and other uses, then this may accelerate a move to urban centers because housing may be more affordable and expansive than it is today (in central cities). To what degree would parking availability even be a factor in residential choice (this naturally depends on the question of private vehicle ownership vs. shared mobility service usage), and how will all of these interacting forces change the urban landscape?

It is also important to note that the policy and regulatory environment and framework will undoubtedly play a major role in shaping future land use development patterns and residential and work location choices. Land use policies and zoning regulations strongly affect various location choices, and the extent to which regulatory authorities and city councils will alter policies and relax or tighten zoning restrictions in response to the introduction of AVs in the marketplace remains rather unclear. In an effort to avoid zero-occupant vehicle (ZOV) induced traffic congestion, cities may adopt rules and policies limiting the extent to which AVs can move around empty. If that happens, there could be a series of cascading impacts that affect how people make residential and workplace location choices in an AV future. Another key question in this context is the extent to which different stakeholders and players will wield influence in shaping land use and location decisions. How will real estate developers, financiers, city councils and policy makers, and consumers interact, and what will be their relative influence in shaping future urban spaces? Will the interactions and influence structures be different in an AV future? What will happen to real estate prices, what types of incentives might cities provide developers to build in the city, and how will reclaimed real estate (from parking that is no longer necessary) be re-purposed for other uses? Answering these questions requires the development of multi-disciplinary teams capable of accounting for complex interactions and forces that will govern the future of land use development and household residential and work location choices.

2.3 Data Requirements to Understand and Predict Longer Term Location Choices

To address the many questions presented in the previous subsection, it is necessary to collect data that provides key insights into the determinants and processes that drive household location choices. It will then be possible to better assess the potential impacts of AVs on household location choices and land use development patterns. Given that AVs remain rather abstract and conjure different images for different people, the design and administration of stated preference surveys that provide reliable data about mobility choices in an AV future remains elusive. As automated vehicles enter the marketplace and people become increasingly familiar and comfortable with the technology, then more reliable stated preference data can be obtained through such surveys. This is not to say that stated preference surveys should not be done; surveys that are designed and administered well can provide valuable information. Analysts should draw inferences, however, from such data with care (given the uncertainty associated with AV technology) and continuously strive to improve the design of AV-related stated preference surveys based on intelligence gathered and lessons learned from prior stated preference surveys on the subject.

Land use patterns, and household residential and workplace location choices, change rather slowly. Unlike mobility choices which may change frequently (even within a single day), location choices exhibit dynamics over a longer period of time. Households move and people change workplaces rather infrequently and it is therefore often difficult to track and identify motivating factors that trigger residential location and workplace location choices and changes. In this context, it would be highly desirable to implement a long term longitudinal data collection effort with a panel survey component (so that repeated data is collected over a long period of time for the same households and individuals) similar to that employed in the medical community to track health of individuals over time and identify factors that contribute to different health outcomes. The longitudinal data collection effort would enable the observation of changes in household residential location choices and person work and school location choices over time, in parallel with changes in socio-economic and demographic characteristics, attitudes and perceptions, lifestyle preferences, technology, and built environment and transportation network attributes. By tracking these aspects over time, it will be possible to better relate changes in longer term location choices to changes in circumstances; in turn, this will enable a more robust prediction of what might happen in an AV dominated mobility future because the longitudinal data offers a mechanism to potentially identify underlying causal relationships at play.

Although there is considerable data about where people live and work (through household surveys), there is very little data about why people choose the locations that they do at various stages of life. A lack of understanding of underlying reasons for location choices hinders the ability to figure out the extent to which a decrease in disutility of travel (brought about by AVs) would affect location choices. Existing household travel surveys or new surveys that focus on location choices should include a battery of questions that ask respondents to indicate how they reached a certain location decision, what tradeoffs were made in arriving at the said location decisions, the importance ranking of various explanatory factors in the location decision-making process, and why they may have moved residence or workplace when they did. What are the changes in lifestyle preferences, attitudes, or lifecycle stage that brought about the changes in location choices over the life course? Insights into the decision-making process will greatly aid in better predicting how AVs may affect location choices in the future. For example, if the data reveal that travel time to work or accessibility to destinations is not a high priority in residential location choice, then it is unlikely that AVs will lead to a further spreading out of the population. In attempting to get at the how and why of location decision-making, the use of quantitatively oriented surveys alone may not be sufficient. The use of focus groups or other qualitative research methods may be warranted to obtain deep insights in underlying decision processes. Technology will continue to evolve rapidly with efforts underway to build flying cars and use drones more effectively in delivering goods and services. With such aerial services increasingly on the horizon, the need to predict location choice dynamics will only grow further; the collection of rich longitudinal and underlying decision process data will go a long way in providing the basis to build robust predictions in response to hypothetical future scenarios.

3 Future Ownership and Use of AVs

3.1 Understanding the Rate of Market Adoption of Highly Automated Vehicles

AVs are coming, but what will these vehicles mean for society? Will self-driving vehicles substantially reduce personal car ownership? Will they increase congestion? Will they reshape urban and suburban development? The answers depend on how they will be adopted and used.

The advent of self-driving vehicles could be truly transformative, but future ownership and use are highly uncertain. There are two parallel paths for the way in which AVs could deploy through the traffic stream: (1) as privately owned vehicles and (2) as mobility service fleets. Potential negative impacts of AVs, such as increased congestion and emissions, are determined by whether AVs will be used as privately owned vehicles, sequentially used on-demand service fleets (with one person being transported at any one time), or pooled (transit-like) mobility fleets.

If we look at ownership versus fleet usage today, the answer seems to be biased toward personally owned vehicles. In the U.S. we find that over 90% of US households own a car. Only 9% of households do not. A Pew Research Center study on the shared economy indicated that only 15% of American adults have used ridesharing apps meaning 85% have never used such apps. The majority of current users of mobility service fleets are vehicle owners and drive a car regularly. The situations in which they use ride-hailing suggest occasional, supplemental usage to their regular driving, such as after drinking alcohol or while traveling. Timing is an issue when combined with the inertia seen in people's preferences for vehicle ownership. People who use ride-hailing still own cars now. But these cars are getting older and AVs are on the horizon. How will this timing affect the type of adoption? Will people not purchase a new vehicle when they have access to automated on-demand mobility fleets? Will non-automated vehicles flood the previously owned car market?

There are factors that point towards early AV deployment through mobility fleets. Fully automated vehicle deployments will need to be near perfect in operations to engender trust among the public and policy makers. Early applications will likely be route-constrained or geofenced. This fits the business model of highly automated fleets, which could quickly begin operating as urban circulator systems. Urban circulator systems such as streetcars and rubber-tire trolley lines, typically operate regular service within a closed loop. One can imagine automated micro-transit vehicles (e.g., shuttles serving 8–10 passengers) operating as urban circulator systems no later than 2020. Such fleets would serve as a prelude to less route constrained, personalized, on-demand automated taxis that would be operated by the ridesharing app or technology companies, such as Uber, Lyft or Waymo. Such on-demand fleets are being piloted across the U.S. and in Europe.

On the privately owned vehicle side, the path to full-scale deployment of highly automated will go slower for a number of reasons. First, the majority of the privately owned vehicle fleet is currently operating at a Society for Automotive Engineers (SAE) International's standard J3016 Level 2. The levels range from 0 to 5, with Level 0 being no automation at all and Level 5 being completely autonomous in all conditions. At Level 2, one or more automated driver assistance systems (ADAS) controls both steering and acceleration/deceleration using information about the driving environment and with the expectation that the human driver will perform all the other aspects of a driving situation. On average vehicle fleets turnover about once every 9–10 years when privately owned (though the turnover is faster when a vehicle is part of a mobility service fleet). So that creates a situation of many needed fleet turnover events to get from Level 2 to a Level 5 vehicle.

Auto makers are pursuing Level 5 automation, with Tesla as the most aggressive example. The company's second-generation Autopilot, released in 2017, has the capacity for full, Level 5 operation, but the company anticipates that it will not have the software capacity to make the cars fully automated in any conditions until at least 2020. Theoretically, a Level 5 vehicle would not require a steering wheel, acceleration or brake pedal. The human driver is totally out of the driving equation. Again, getting a human out of the driving equation better fits the business model of mobility service fleets; without drivers the fleets could be operating at great profit margins.

Regulation may hinder AV deployment as privately owned vehicles. Level 5 vehicles entail drive anytime, drive anywhere AV operations. But the fact that many road operators have not fully implemented or even anticipated required “rules of the road” for highly automated vehicles means that they will likely be constrained in some ways, especially at early stages of implementation. An owner of a private vehicle may not want to pay a high purchase price for a vehicle that is constrained in its sphere of operations (i.e., either route constrained or geofenced). Anticipating this, some automakers are positioning highly automated vehicles as potential peer-to-peer vehicle sharing for owners to earn money when they are not directly using the vehicles. It is unclear how desired this type of peer-to-peer car sharing would be among vehicle owners.

3.2 Identifying Early Adopters of Highly Automated Vehicles

The social, economic, market, and policy dynamics of the paths to deployment of highly automated AVs, chart an uncertain future at this point in time. Research methods at this stage are in monitoring industry trends and undertaking studies of attitudes and opinions, which measure acceptance. Acceptance influences adoption.

Past research has indicated that attitudinal variables are significant predictors of acceptance and use of self-driving vehicles. It does not really matter whether one is a millennial or a baby-boomer; what matters in terms of acceptance and adoption are other variables, such as trust in the technology or where one falls on the technology adoption curve—early, late, or laggard. If a person is one of those who lined up early on the first day that the iPhone 10 was available (whether really needed one or not), research indicates that person is more likely to be among the first people lining up to use a self-driving car.

How do researchers test hypotheses such as these, if highly automated vehicles are not yet available for everyday use? In the U.S. and Europe, researchers have a perfect opportunity with the ongoing AV pilot studies. Such “experiential” analogs can inform future uncertainty; for example, by examining whether the experience, attitudes and opinions of AV pilot participants differ (or not) from those who are non-participants. Does the experience of being a pilot participant affect preferences for owning or sharing AVs? Methods that could be used to examine such outcomes, include interviewing drivers, asking specific follow-up questions to large-scale travel surveys, using real-time tracking of travel behaviors, and monitoring changing attitudes and opinions. Research could set up experiments in which chauffeurs serve as proxies for the use of AVs.

To understand future behavior in the context of AVs, we can research how people are using shared mobility now. Many people hypothesize the current ride-share users will be early adopters of AVs. Sharing is often seen as a good way for people to experiment with automation. Such research is being conducted currently in Germany with self-parking vehicles.

The Texas A&M Transportation Institute (TTI) recently completed a study [1] that looks at the experience of current ride-hailing fleet users as an analog to future AV usage. Ride-hailing fleets could be considered a future mobility technology. The TTI research confirms that current ride-hailing users (such as users of Lyft or Uber) are more likely use self-driving vehicle technology than non-users—by margin of almost 2–1. Also, the longer people have been using ride-hailing services, the more likely they are to be early users of self-driving vehicles. Similarly, another published study from the University of Texas at Austin [2] indicated that green lifestyle preferences and who are tech-savvy are more likely to adopt car-sharing services and use ride-sourcing services. Also, these individuals, and those who are young, reside in urban areas, currently eschew vehicle ownership, and have experience/used ride-sourcing services are especially likely to be early adopters of AV sharing services. Why are these results important? For three reasons:

- The rate of growth of the ridesharing market in a city may be a good estimate of the rate at which the future self-driving market may evolve.
- Characteristics of rideshare users define characteristics of early users of self-driving vehicles.
- Their travel patterns inform early application areas.

What eventual impact might this technology have on cities in terms of congestion and land use? The answers depend on whether self-driving vehicles will be used as privately owned vehicles or as vehicles in a mobility service fleet, like a car-share service (e.g., Car-2-Go, Zipcar) or ride-hailing (e.g., Lyft). The early adopters of self-driving vehicles will use them as ride-hailing fleets rather than as privately owned vehicles—by a margin of more than 2–1. Why? Cost and convenience (less cost; more convenient than owning one's own self-driving car). Important research questions under this topic include whether having a driver or not affects pooling behavior. In some cases, customers might view the driver as a neutral moderator. On the other hand, not having a driver in the car might discourage customers from getting in the car with other people for pooling. One creative data collection tool to explore this question would be to establish a blog and have people who are using pooled services post about their experiences. Given the amount of uncertainty there is related to this topic, it might be best to focus on qualitative data because researchers can keep probing and asking deeper and more complex questions. For example, a researcher might sequentially introduce new information or a new scenario and gauge how people's choices change throughout the interview. The degree to which early adopters will use "pooled" versions of self-driving determines whether we have greater traffic congestion and/or vehicle emissions in urban areas. Specific policy interventions may be necessary to incentivize such behavior.

4 The Potential Implications of AVs on Activities-Travel-Choices and the Travel Environment

4.1 Possible Travel Responses to Highly Automated Vehicles

The true implications of AVs on our activity-travel behavioral patterns may not be known for a long time. But, based on past behavioral studies, we are at least able to project possible travel responses to this new technology. For instance, as already indicated, people may locate themselves farther away from workplaces, since the commute is less of "getting stuck in traffic" and perhaps more of quality time in "our private cocoons". Similarly, individuals may be more open to traveling long distances to participate in desired activities at desired locations. These kinds of effects challenge the conventional notion present today in the real estate and urban planning fields that it is all about "location, location, location", and may lead to developers building activity centers more dispersed in space because there is little premium attached to location and travel time does not impact accessibility and land value. So, perhaps our cities will become more sprawled with larger geographic footprints, leading to higher dependence on motorized cars, lower public transportation use, and less walking and bicycling. Further, because cars are "driverless", and people may spend more time in their vehicles getting to desired locations, there may be a higher demand for larger vehicles that provide more space and are retrofitted with more comfort-oriented amenities. At the extreme, imagine recreational type vehicles being increasingly used for urban travel! Such large vehicles can reduce roadway processing capacity. And then, because people do not need to chauffeur their children (the so called "soccer mom" phenomenon) or other mobility-challenged household members, they may find themselves with more time in the day that they then use to travel more to pursue desired activities. And what might happen to public transportation as we know it today? After all, AVs combine the advantages of public transportation (such as catching up on news, texting friends, etc.) with that of traditional private vehicles (flexibility, comfort, and convenience). So, for example, should we be even investing in high capital high-speed rail systems? When AVs come into being, what would be the incentive to use high-speed rail systems when individuals can travel (and sleep) in AVs? Indeed, individuals may travel mostly in the night time to get to vacation destinations. The issue that will likely distinguish high speed rail and AVs would be the travel time difference and cost. But travel time may be less of a consideration, because people can use that time as they please in AVs (especially if there is also the move toward larger, more spacious and comfortable vehicles). Related to the above point, travelers can still exercise control over the parameters of the routing of AVs, and may choose routing options to include longer routes if they are, for instance, more scenic. The effects above could result in an increase in vehicle miles traveled, traffic congestion, emissions, and energy consumption.

But, just to be sure, and before we run away to label AVs as being an unwelcome technology and dismantle all plans for those public transportation investments, consider the other side of AV impacts. If AVs were to be made available to the public in the form of a shared ride service, ride-sourcing may become appealing to a large segment of the population. One extreme scenario is that nobody owns a vehicle anymore and everyone uses driverless cars provided by ride sourcing enterprises. In such a case, all public transportation trips become a "kiss-and-ride" event without the need to "park, walk-and-ride", which can then increase public transportation attractiveness. Ride-sourcing arrangements can also serve to cut out low volume routes, and enhance public transportation service on high volume routes, which then can have a positive reinforcing effect of increasing transit ridership on those routes. Besides, because any single vehicle is parked for much less time during the day in a car-sharing configuration, there is substantially less need for parking structures across the city (parking structures can take up to a third or even more of the land-area in cities). This reclaimed area can be used for developing green areas or for additional economic development. From an enhanced accessibility and a social justice standpoint, those who are usually unable to drive or who restrict their movement because of driving challenges (e.g., the elderly, disabled, and children) can be more mobile, reducing the social exclusion of such individuals and enhancing their quality of life. Additionally, from a traffic processing capacity standpoint, AVs could change the capacities of highways and intersections, reducing delays and congestion, and increasing travel time reliability, a positive benefit in terms of emissions and energy independence (though one must also be cognizant of the fact that reductions in delays and congestion, and improvements in travel time reliability, can itself engender more travel that can offset some of the benefits). For example, AVs can reduce the distance between cars, allowing platooning and an increase in the capacity of travel lanes. With the potential ability of AVs to accurately position themselves within lanes, lane widths can be reduced to allow for more capacity without the physical expansion of highways. With the potential ability to process vehicles at intersections as cars arrive rather than a traditional signal control, an intersection may be able to process more vehicles (though driverless car technology may also necessitate lower accelerations and decelerations at intersections than human-driven vehicles because passengers are known to be more sensitive to speed changes than drivers, which can then offset some of the capacity benefits of AVs). Further, commercial vehicle operations can be pursued during off-peak and night times, reducing demand on urban highways and further reducing delays to urban travelers.

Regulations (or lack thereof) will undoubtedly have a large effect on the potential outcomes by limiting or encouraging travelers to choose one or more new modes (ride-hailing, ride-sharing, car-sharing, bike-sharing etc.). Pricing will be the other critical component in how travelers will choose new modes or new technologies; this is also related to taxes imposed by regulations. Dynamic pricing is an effective method to influence when people choose to travel. U.S. cities have had difficulty competing with the low cost of owning a vehicle and may change with more opportunities to travel easily without owning a vehicle.

4.2 The Transition Period

Of course, the transition from our human driven world to a world with only AVs will not happen overnight. Indeed, one could argue that, in a democratic society, AVs will never completely replace all human-driven vehicles. Some people who are technology-inclined and savvy may lead the trend to embrace AVs, while others who are intrinsically skeptical about technology and do not want to yield control to a machine may be the last to jump on-board (if at all). Eventually, it is possible that government policy could require a completely driverless world even in democratic societies. In any case, there will be a long period of time (perhaps three to four decades or more) of a mix of human driven and AVs on the roadways. This intervening period will be a challenging one, with many safety, security, and privacy issues to be resolved and ironed out. But governments and transportation agencies need to be thinking forward, anticipate potentially unintended consequences, and formulate policies to facilitate the movement toward a new way of traveling and to reduce the potentially offsetting effects of AVs.

4.3 Research and Data Needs to Predict Activity-Travel Impacts

While the previous sections listed a whole array of possible implications of AVs on activity-travel choices and our travel environment, there are important research and data needs that, if pursued, can better inform the potential activity-travel impacts of AVs. Some of these needs have already been identified in previous sections, because AV usage and operations (private AVs vs. ride-sourcing AVs) and land-use impacts immediately have impacts on activity-travel choices. In addition, there needs to be a better understanding of (a) how value of time for different activities may change under scenarios of large-scale penetration of AVs, (b) individual perceptions and desires about alternative uses of time freed during travel, (c) the aspirations, concerns, mobility needs, and willingness-to-pay to acquire/participate in ride-sourcing AV services amongst different population groups, and (d) the rich interplay between virtual and physical (in-person) activities as AVs blur the distinction between these types of activities.

In terms of data needs, existing data available for usage patterns for mobility-on-demand services is available only at aggregate level. There is a need for disaggregate level data with socio-demographic and economic indicators of users to identity demographic segments with high affinity to such services. A focus on activity-travel patterns (and needs) of specific segments such as senior citizens/ restricted mobility individuals (especially in rural areas with limited access to urban transport modes) and young millennials may also be beneficial as such segments are likely to be early adopters of AVs. Also, detailed information on time-use and activity scheduling characteristics (such as stop-making in tours, multi-modality, person accompaniments during travel) is warranted. Such disaggregate-level data, including both virtual activities and in-person activities, are important to estimate activity-based models, which are much better than traditional trip-based models in capturing the changing prism of time-space interactions engendered by AVs. In addition, the critical importance of attitudinal and lifestyle measures in determining AV adoption and the paradigm of adoption, as well as the value of time, security, privacy, and cost perceptions, implies that activity-travel surveys should elicit information that helps to develop appropriate psychometric indicators, perhaps based on existing scales borrowed from social psychology. Further, because of changing penetration rates of AVs over time, it is important to consider panel data collection, or at least repeated cross-sectional data collection, at frequent intervals (say at least every two years rather than once in a decade).

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Judging a Car by its Cover: Human Factors Implications for Automated Vehicle External Communication

W. Andy Schaudt and Sheldon Russell

Abstract This chapter presents a summary of the 2017 AVS Breakout Session 2.1, Judging a Car by its Cover: Human Factors Implications for Automated Vehicle External Communication. The session was scheduled for four hours with half the time dedicated to presentations from three speakers and half the time for interactive exercises. The three speakers presented on a range of topics which included related research projects across multiple different countries, as well as activities underway exploring the potential value of international standardization. Key points included the importance of communicating vehicle intent, the need for investigating the unintended consequences of deploying new forms of communication, and the need for automated vehicles to be consistent in the design of these new interfaces.

Keywords Automated vehicles · Highly automated vehicles · External communication · Human factors · External signals · Human-machine interface

1 Introduction

Road users communicate with one another in numerous ways. Explicit forms of communication include things like hand gestures and head movements. There are also implicit forms of communication such as eye contact [1]. When situations occur that result in conflict between road users, such as right-of-way uncertainty, direct interaction between the humans involved can be critical to successfully resolving the issue. Uncertainty exists as to whether highly automated vehicles (HAVs) will be able to perceive and communicate intent in the same ways that a human can. Therefore, we should design HAVs with communication capabilities

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that can signal their intent in ways other roadway users can reliably understand. Recent research investigating HAV external communication found that three different signals communicating vehicle intent can be robustly communicated and consistently interpreted by road users [2]. If successful, automated vehicle external communication would enable road users to make judicious decisions during uncertain situations and may even lead to greater trust by the public.

This breakout session was developed to explore how HAVs should communicate with different roadway users, what information is needed to communicate, and to what degree standardization of HAV external communication could be valuable. To accomplish this, the authors invited experts currently performing research on this topic to provide brief presentations on their work. In addition, there were three breakout exercises performed to further explore use cases of HAVs and their interactions with other vehicles and vulnerable road users. The goal of these exercises were to evaluate the complexities of each scenario and to explore how the application of human factors design principles could lead to potential solutions to these challenges. In Sect. 2 we present summaries of the presentations by invited experts. Section 3 will describe the exercises that were performed by all those in attendance. Finally, Sect. 4 will provide highlights of the discussion that was generated and potential research needs that were identified.

2 Current Research in HAV External Communication

2.1 Presentation Summaries

2.1.1 Current Activities on HAV External Communication from the International Organization for Standardization (ISO)

John Shutko from Ford Motor Company presented on current activities from the International Organization for Standardization (ISO) regarding HAV external communication. Mr. Shutko described an ISO meeting that was held in Gothenburg Sweden in the spring of 2017, which included various international contributors who attended and presented in a special all-day session on multiple research activities investigating the use of HAV external communication. The goal of this session was to explore the topic and determine if a task force should be formed to explore the need of potential standardization in the near future.

Mr. Shutko described some of the highlights from the session. One point made was the importance of context during interactions between road users. Therefore there is potential for communicating more than just the HAV state, such as HAV intent. Another point made was that not only should HAV external communication signals be perceptible and communicable, but most importantly they should be learnable. The vast majority of signals, if not all signals, are not immediately understood on the first exposure. According to Mr. Shutko, an ISO task force was underway and planning to produce a technical report that would act as a guidance for developers of external communication systems for HAVs. The main objective of the document is to propose how HAVs could communicate with other road users based largely on current and past research across various countries.

2.1.2 Effects of Non-verbal Communication Cues on Decisions and Confidence of Drivers at an Uncontrolled Intersection

Dr. Satoshi Kitazaki from National Institute of Advanced Industrial Science and Technology (AIST) presented the results from a research project that investigated how current road users use non-verbal cues and how these change drivers' actions and confidence. The specific research question under investigation was "when and how do vehicle behaviors and hand gestures influence drivers' yielding decisions and confidence at an uncontrolled intersection?" The procedure first required participants to review a video of the intersection for calibration. Next, each participant received verbal explanation from the experimenter about the scenario(s) of interest and the associated cue, and watched as the experimenter demonstrated one of the two hand gestures. Finally, each participant reviewed a schematic computer animation showing the plan view of the intersection and the two moving cars, and then provided a subjective rating of yielding frequency and confidence level. Results showed that hand gestures were especially effective at influencing driver behavior when combined with vehicle behaviors. This led to further discussion from those in attendance on the implications for the design of future external communications systems.

2.1.3 Needs of Pedestrians Interacting with Automated Vehicles

Dr. Ruth Madigan from the University of Leeds presented on the needs of pedestrians when interacting with automated vehicles. Dr. Madigan provided a foundation of the human factors implications when there is no driver in the vehicle, and also presented a summary of multiple prototype signals currently being investigated by numerous different companies and researchers attempting to find a replacement for the missing gestures that will be lost when HAVs are deployed. Dr. Madigan pointed out that external communication requirements may change based on the HAV design and utility. For example, should an automated shuttle communicate differently than someone's personal HAV? Additionally, the design and results from the CityMobil2 project were presented and discussed. This project used interviews, focus groups, and on-site interviews to explore participant acceptance and interaction with HAVs across multiple sites. Participants reported that they were most interested in knowing whether or not the HAV had detected their presence. Modality of communication was also discussed, but there was no clear consensus about the best modality across the different research sites.

Additional comments from focus groups were also reviewed, including the ability to see messages from HAVs, and the responsibility of the ‘driver’, and the use of dedicated versus shared spaces for HAVs.

3 Breakout Exercises

Organizers prepared three exercises based around roadway scenarios (use cases) that would help generate interaction and discussion among attendees on the human factors implications towards HAV external communication design. Each use case is briefly described below.

3.1 Use Case A: Park, Pickup and Proceed

The purpose of Use Case A was to provide an example a taxi approaching a passenger on the side of the road to pick up and transport. This use case was demonstrated by showing a video recording from a study vehicle’s forward facing camera mid-roadway in Virginia. A screenshot from a video frame can be seen in Fig. 1.

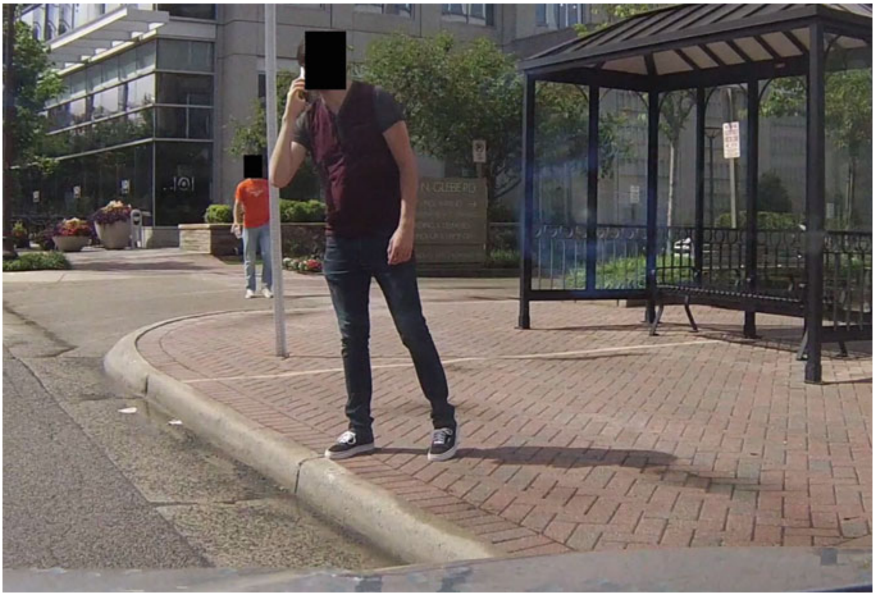

Fig. 1 Screenshot from video representing a taxi approaching a passenger for pickup

Attendees were instructed to answer a series of questions to help generate discussion about human factors implications on external communication design. For Use Case A, these questions were:

- Can you identify relevant road user types, locations, and characteristics that could affect interpretation of external communication in this scenario?
- What road user types can you identify (other vehicle drivers, pedestrians)?
- Where are each road users' locations in reference to the HAV?
- Can you identify pedestrian characteristics that could affect interpretation of external communication (e.g. knowledge transfer, assumptions, expectations)?
- What different stages of HAV state did you observe (e.g. steady forward motion, deceleration, stop, acceleration)?
- Can you identify the HAV intent and explore conflicts (if any) with HAV states?
- In this scenario, should HAVs communicate state, intent, or both?
- How should the HAV communicate (visual, auditory, both)?
- What human factors design principles should be considered when designing an external communication system for this use case (e.g. visibility of system status, consistency and standards, match between system and real world)?

3.2 Use Case B: HAV Encounters Vehicle Entering Roadway

The purpose of Use Case B was to provide an example of a common roadway conflict that occurs as one vehicle is moving along in the right lane while another vehicle is about to enter the roadway and then required to merge into that occupied lane. This use case was demonstrated by showing a video recording from a study vehicle's forward facing camera acting as an HAV with another vehicle entering the highway on the right side. A screenshot from a video frame can be seen in Fig. 2.

Attendees were instructed to answer a series of questions to help generate discussion about human factors implications on external communication design. The same questions used in Use Case A were used for Use Case B.

3.3 Use Case C: Right-of-Way Conflict

The purpose of Use Case C was to provide an example of a common right-of-way conflict that occurs at signalized intersections between a vehicle approaching an intersection with a green traffic light and a pedestrian walking across the HAV intended path on a crosswalk. This use case was demonstrated by showing a video recording from a study vehicle's forward facing camera at an intersection in Virginia. A screenshot from a video frame can be seen in Fig. 3.

Fig. 2 Screenshot from video of a vehicle entering the roadway on the right

Fig. 3 Screenshot from video representing a right-of-way conflict between a pedestrian and vehicle

Attendees were instructed to answer a series of questions to help generate discussion about human factors implications on external communication design. The same questions used in the previous two use cases were used for Use Case C; however, there was one additional question added:

- Can you identify any right-of-way roles and conflicts?

4 Discussion and Research Needs

During each of the exercises, attendees engaged in substantial discussion. This discussion resulted in some outstanding questions and research needs for future consideration. Highlights from the discussion are presented below:

- Will HAVs be able to sense or detect the intent of other road users? Or will we need to rely only on one-way communication (e.g. vehicles display their intent but do not recognize other road user behavior)?
- How will HAVs respond to, and communicate with, emergency vehicles?
- Road user intent changes over time, and has the potential to change very quickly. When and how should these changes be communicated?
- What and how much information that is displayed to external road users (e.g. pedestrians, other drivers) should also be displayed to internal passengers/operators?
- Is it possible that these external communication strategies could actually extend a conflict/event rather than resolving it?
- What is the effect of roadways changing between shared or dedicated, and how should this be communicated to all road users (if at all)?
- Should HAV external communication be ‘sociable’? This might include emotion expression, regional variations/dialect integrated into communications.
- How does social responsibility play a role in communication between HAVs and other road users? Will pedestrians intentionally step in front of HAVs because pedestrians know it will stop regardless of any signaling?

This breakout session not only included presentations from experts currently researching the topic of HAV external communication, but also provided a series of exercises using specific use cases to generate substantial discussion towards identifying new research questions not yet explored. Some important takeaways included the need for continued research in a variety of real-world environments across numerous different cultural and geographic regions, the importance of communicating HAV intent, and finally that external communication consistency across the automotive industry is needed to minimize any road user confusion as HAVs are deployed onto our roadways.

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Training and Education: Human Factors Considerations for Automated Driving Systems

Anuj K. Pradhan, John Sullivan, Chris Schwarz, Fred Feng and Shan Bao

Abstract Vehicles with partial automation, forerunners to those with higher levels of automation, are already being deployed by automakers. These current deployments, although incremental, have the potential to disrupt how people interact with vehicles. This chapter reports on a discussion of related issues that was held as part of the Human Factors Breakout session at the 2017 Automated Vehicle Symposium. The session, titled "*Automated Vehicle Challenges: How can Human Factors Research Help Inform Designers, Road Users, and Policy Makers?*", included discussions between industry experts and human factors researchers and professionals on immediate human factors issues surrounding deployment of vehicles with Automated Driving Systems (ADS).

1 Introduction

Vehicles with lower levels of Automated Driving Systems (ADS) [1], currently already deployed on public roads, are forerunners to those with high levels of automation (L3+). While current deployments are relatively incremental and

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tentative, they have the potential to induce disruptions in the way people have traditionally interacted with vehicles. These disruptions will likely affect all road users—drivers of advanced vehicles, drivers of 'legacy' vehicles, pedestrians, and bicyclists. Significant gaps in our knowledge about users' expectations, their perceptions, their strategic and tactical use, and especially their understanding of these systems limit our ability to anticipate how adoption of these vehicles with ADS will play out on real roads, in real time, with real limitations, and representative use cases.

As long as a driver is responsible for the supervision of these systems, human factors research will be tasked with predicting their direct effects on driver behavior and decision-making. It is also essential to understand their indirect effects on associated stakeholders, including manufacturers, policy makers, educators, and local legislators. Education, training, and effective human-machine interface (HMI) design can play critical roles in raising driver/road-user awareness to ensure clear understanding about appropriate use of and expectations about these and future vehicle capabilities.

To that end, experts were identified and invited from academia, government, and industry, and a meeting was convened to learn about and discuss issues from different perspectives, with diverse insights on various approaches to address them. This workshop was built on two successful Human Factors workshops conducted by the authors on related topics at the Transportation Research Board Annual Meeting in January 2017, titled "*Acquisition and Maintenance of Driving Skills in the Climate of Driver Support, Driver Assist, and Automation Systems*", and "*Driver Adaptation to Automation and Advanced Driver Assistance Systems*". These two workshops laid the groundwork for the conceptualization and organization of this particular workshop under discussion as a half-day human factors breakout session at the Automated Vehicle Symposium in July 2017, in San Francisco.

The intent of this workshop was to provoke a discussion among industry, government, and academic experts with broad perspectives of the likely consequences that various levels of vehicle automation will have for humans adapting to these new technologies. The workshop deliberately sought experts outside of the usual human factors research community in an effort to understand those indirect effects that extend beyond immediate issues of vehicle control and operation, especially since the expectation is that automation may alter how people have traditionally thought about mobility, with such changes likely having consequences on the behavior of all road users. An end objective was to identify relevant emergent themes and discuss research gaps and needs based on discussions between experts and participants.

2 Panelists, Discussion, and Emergent Theme

The workshop was anchored by an expert panel who provided insights into issues in vehicle automation, in the context of human factors, as perceived through the lenses of their respective domain. These panelists were identified based on their expertise and relevance to the field of automated vehicles, with the criteria that the panelists were not actually human factors professionals. The four expert panelists were: Dr. Bernard Soriano, Deputy Director, California Department of Motor Vehicles; Dr. Nidhi Kalra, Senior Information Scientist and Director San Francisco Bay Area, RAND Corporation; Emily Frascaroli, Counsel, Ford Motor Company; and, Alex Epstein, Senior Director, Digital Strategy and Content, National Safety Council. The workshop was moderated by Edward Niedermeyer, an auto-industry analyst.

To stimulate active discussions, the panelists provided an introductory overview of their perspectives on the critical issues related to deployment and acceptance of vehicles with advanced driving systems. The topics that were presented included opinions about regulatory issues at federal and state levels, about evidence-based approaches to assessing risks, about rule making for public deployment of automated vehicles, and about public information campaigns for educating potential users of future automated technologies.

In keeping with the objective of this workshop, which was to foster an environment conducive to stimulating discussions by convening experts from academia, industry, and government, the intent behind the panelists presenting their perspectives on the most critical topics in automated vehicles was to address topics and introduce scenarios to catalyze discussions and provoke questions. This approach proved to be successful, as indicated by the level and content of discussions that were conducted after the panel sessions and as a part of the question and answer sessions. The discussions and the Q&A covered a number of topics and issues, both related to the topics that were discussed by the panelists, and otherwise. The remainder of this chapter will briefly list the various sub-topics that were discussed, and then address in more detail the emergent theme identified from the discussions. The topics discussed mainly covered trust and acceptance, levels of automation as it relates to risk acceptance, regulatory aspects of safety and enforcement, misuse of technologies, mental models, and education and training. From these, the emergent topic that the discussions coalesced around was in the domain of education and training, with it having a relevance for almost every other topic discussed. The rest of this chapter addresses the relevance of this topic in the automated vehicle domains, as informed by both the discussions at the session and by the scientific literature.

3 Training and Education in Context of Automated Driving

There has been significant progress in automated driving systems, with vehicle safety evolving from passive safety such as seatbelts and airbags, to active advanced safety technologies designed to prevent crashes. These technologies increase safety via driver assistance systems that take some level of control of the vehicle. This means that, as these technologies become deployed, a dramatic shift in the driver-vehicle relationship will manifest. A driver whose traditional role has been that of an engaged operator will be relegated to that of a supervisory controller of an automated system [2, 3].

Despite all promises, we can still expect that most automated systems will have limitations and may not work seamlessly under all conditions. It is therefore critical that drivers understand the system limitations and system capabilities, are able to safely and efficiently take over or cede control from or to the automated systems, and appropriately trust the system. These two aspects, knowledge and trust, will play a significant role in ensuring that unintended safety-related consequences of advanced vehicle automation do not manifest as these systems become commonplace. For both of these constructs, the discussions and the consensus remain that the most tenable manner of mitigating risks is through appropriate education and training. Education and training will increase and improve one's understanding of a system, its capabilities and limitation, and the role of the human operator in this context, which in turn can contribute to increased and more accurate trust in the system. These two aspects are discussed separately below.

Knowledge Understanding the changes in vehicle capabilities and the shifting roles and responsibilities of the driver is not obvious [4]. For example, the University of Iowa [5] recently surveyed over 2000 drivers in the US to examine their understanding of advanced vehicle technologies. The survey asked about the following advanced safety technologies: antilock braking system (ABS), adaptive cruise control (ACC), back-up cameras, back-up warning system, forward collision warning system (FCW), tire pressure monitoring system, lane departure warning (LDW) system, and blind spot monitoring system (BSW). The respondents generally showed low levels of consumer knowledge for these technologies. The majority of the respondents also reported that the driver remained the most important component of driving, with a belief that the highest frequency of crashes was due to drivers operating the vehicle under conditions when they should not have been. These findings reflect a perception that the role of the driver in a vehicle is still to control the vehicle and that automated systems are not yet in control. However, with deployment and further advances in automation levels, this situation will change.

As these systems get deployed, it will be the case that consumers have zero or minimal experience with the technologies. Thus, there is a critical need for drivers to clearly understand these systems, understand their capabilities and limitations, understand their operational domain, and understand the driver's roles and responsibilities with the new paradigm in driving safety. This particular need has indeed been identified by the National Highway Transportation Safety Administration (NHTSA) as critical, and they have listed driver training and education as a critical human factors area in their 2013 automated vehicle policy statement [6].

Given that it is knowledge, or lack thereof, that forms the bases for best taking advantage of the safety benefits of automated driving systems, it seems evident that well designed and targeted training may be beneficial towards helping drivers gain accurate, complete, and calibrated trust in automated systems. Similar targeted training has been used in the driving domain to accelerate the gaining and retention of higher order hazard anticipation skills in novice drivers [7, 8]. Similarly, a study conducted by the University of Iowa [9] examined the effects of training and education, in the form of various training protocols, on drivers' attitudes and knowledge of advanced driver assistance systems. In this latter study, the training approaches included information received via an owner's manual and observing the use of the systems during an on-road demonstration. It was found that participant knowledge increased significantly after training, the participants' ratings of usefulness of technologies increased significantly, ratings for trust increased significantly, and apprehension decreased significantly.

Trust Another critical aspect of this issue is that of trust and expectations. Despite promised benefits of automation, there are new sources of risk. One such risk is the misuse of automation, characterized by an absolute reliance on automation without the acknowledgement of potential limitations [10]. Such misuse can result in a degradation of the operator's performance of the new tasks that they are responsible for, such as inadequate monitoring of automation functions. Such "automation-induced complacency" [11, 12], given its role in reduced operator performance, is a critical human-factors issue in human–automation interaction [13]. This complacency, or lack of knowledge or acknowledgement of potential limitations of systems, can result from an operator wrongly over-trusting the system or having mis-calibrated expectations of its capabilities.

If there are limitations in automated driving systems, which invariably there will be, mis-calibrated expectations and trust can have a critical impact on the effectiveness and hence the safety benefits touted by these systems [10, 14]. If a driver uses the automation beyond the capacity of the system, he/she is 'over-trusting' the system, and therefore compromising driving safety. On the other hand, if the driver does not use the automation in the conditions for which it has been designed, the driver is 'distrusting' the system and thus is not taking advantage of potential safety benefits. Both of these are related to driver's understanding of the systems, with research showing that over-trust of systems is associated with lower knowledge of limitations of the system [4]. Also, drivers' trust in a system increases with increased knowledge about capabilities and limitations prior to use.

These issues with trust can also potentially be addressed by education and/or training designed to target a user's understanding of a system. People gain an understanding of a system and of phenomena by constructing mental models or schemas [15] which allow them to make sense of a system, to predict outcomes, and to determine responses. These models are initially incomplete and basic, but with exposure, evolution, and new information these models update and solidify. Complete, accurate, and well calibrated mental models, therefore are critical to reducing mis-calibration of trust.

Research on training in automation shows that simply informing operators about the limited reliability of automation and instructing them to always verify the state and recommendations of a system does not sufficiently reduce complacency [16]. However, research also shows that directly experiencing failures of automation, even if they are representing relatively rare events, results in a decline of trust in an automated system. Similarly, training where operators are shown false advice (or false alerts) presented by an automation has shown to be another method to reduce complacency [17]. Essentially, Bahner et al. [17] show that actual experience of automation failures may be better as a training strategy as compared to merely being instructed that such failures may occur, and that operators who actually experienced automation failures during training were less complacent than operators with only instructions.

These findings indicate that appropriately designed training, so as to reduce over-trust, can help mitigate complacency issues. It also indicates, however, that designing training to prepare operators to work with automated systems can be a complex enterprise. For one, simply calibrating the levels of trust may be a delicate balance to reduce complacency but maintain adequate use of the system's automation benefits. With more complex systems, adaptive training may be required, wherein operators' trust towards multiple components of complex systems may have to be tailored appropriately [18]. These multiple components may have to be categorized for different levels of reliability, capabilities, and limitations, to address any adaptive or tailored approaches to training.

4 Conclusion

This chapter started by providing a background of the human factors issues with AV deployment providing a rationale for the workshop. It then provided an overview of the expert panel, the discussions that emerged from the panelists, the discussions that emerged from the interactive sessions between the panelists and the predominantly human factors audience, the emergent theme from the discussions, and a focused section on that topic.

In this workshop, as was the intent, panelists and the audience engaged in a lively discussion about the human factors relevant issues, as seen from the perspective of the industry and lawmakers, in the context of automated vehicle deployments. The main emergent theme was the importance of education and training as an underlying factor in almost all of the issues that were identified and discussed. Based on the importance of this topic, this chapter focuses significantly on it, with the content being based on the discussions, the questions asked, and from the literature.

A summary of key points that resulted from the discussion follows:

- Education is a critical element of automated systems, for all levels of automation.
- The topic of education, as a research gap, will continue to widen if not addressed.
- Customer acceptance will depend on risk assessment, which in turn has implications for education and awareness.
- People are creative and will find ways to misuse systems. Design, training, policy, and enforcement may be critical to reduce abuse or misuse.

A list of suggested action items did emerge from the discussions, as listed below:

- New education models need to be adopted. Realtime training, contextual training, in-vehicle training all may need to be considered.
- Licensing and training requirements must be examined.
- There is a need to establish the institutions responsible for appropriate training.
- There is a critical need to close the gap between reality (real capabilities of a system) and the capabilities implied as a result of marketing.
- Drivers should be made aware of system limitations.
- Drivers should be familiarized with potential skill degradation and strategies to mitigate further degraded responses due to deskilling should be explored.

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Automated Vehicles (AVs) for People with Disabilities

Sudharson Sundararajan, Mohammed Yousuf, Murat Omay, Aaron Steinfeld and Justin M. Owens

Abstract This chapter presents insights from the AVS 2017 Breakout Session 24, *AVs for People with Disabilities.* The focus of this session was on creating awareness about the transportation needs and challenges that people with disabilities face. The emphasis was on how embracing universal design principles in developing AV technologies can make a significant difference in catering to all types of users equitably. Some of those design principles include enabling standards harmonization, data needs, and partnerships, as well as addressing policy barriers and technology challenges. The session was interactive with short thought-provoking presentations, and discussion questions. The discussions resulted in research topic recommendations for the United State Depart of Transportation's (USDOT's) Accessible Transportation Technologies Research Initiative (ATTRI) Program.

Keywords Universal design · People with disabilities · Older adults ATTRI · Automated vehicles

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1 Introduction

In 2010, the U.S. Census reported that approximately 56.7 million people in the United States had some type of disability [1]. Inadequate mobility and transportation provisions can hinder people with disabilities and older adults from completing essential tasks such as obtaining and maintaining employment, keeping medical appointments, pursuing education, shopping for groceries and running errands, enjoying recreational activities, or attending social events, all of which many people take for granted. The USDOT's ATTRI Program [2] aims to provide technology-based transportation solutions for people with disabilities and older adults by leveraging recent advances in vehicle, infrastructure, and pedestrian-based technologies, as well as accessible data, mobile computing, robotics, artificial intelligence, object detection, and navigation. These technologies are enabled by established wireless communications that connect travelers and their mobile devices, vehicles, and roadside infrastructure. This linked transportation system provides mobility options and allows seamless travel for everyone.

AVs and other complementary technologies have the potential to support many transformational changes to the lives of people with disabilities. During the development stages of AV technologies undertaken both by the public and private sector organizations, it is important to explore pathways to ensure that those new technologies are accessible, designed for and available to everyone. This breakout session invited key technology developers, stakeholders in the disability community, and other industry experts to explore different aspects of this development process including several key elements such as universal design principles, inclusive Information Communications Technology (ICT), institutional and policy barriers, interoperability, and standards harmonization.

The session was designed to have two panel presentations. The panel presentations were focused and limited to five minutes to introduce topics and provide background information for people to react. A set of questions were used after each presentation to facilitate discussions with the audience.

2 Panel Discussion 1

The first panel focused on design related AV topics such as: user needs and challenges, universal design principles for AVs, data needs and institutional and policy barriers.

The disability community is heterogenous with many people that have distinct needs and face distinct challenges while taking a trip. Mundane travel choices such as dining out, buying groceries or doing laundry can be a difficult endeavor for people with disabilities (both physical and cognitive). Ease of such activities depends on time of day, available travel modes, location of destination, etc. For example, today's navigation systems show optimal route for a typical traveler, but are not designed to show optimal routes for people with disabilities or older adults who have different needs [3].

AVs are expected to greatly benefit people with disabilities. To benefit this target population group, it is important to design certain features appropriately. As a result, it is critical that AV design teams consider universal design principles to cater to different needs and challenges of people of all abilities. Universal design is a market-driven process intended to create environments that are usable by all people [4]. These principles also apply to infrastructure elements that support AV technologies and applications. For example, consider inclination of sidewalks or access ramps for transit vehicles. A 1:6 slope is considered manageable but a 1:4 slope can be dangerous for wheelchair users [5].

Along with universal design principles understanding data needs for a variety of applications catering to people with disabilities is important. Additional data elements may be needed to provide detailed information to address unique needs of various disability types. For example, consider AV interaction with users who are blind or have low vision. Information on location of door handles, emergency stop button, outside landmarks, etc. need to be communicated via audio. The output data format and delivery type provided must add value to the user. A framework can be developed to understand such needs and ultimately help establish standards that can bring about greater interoperability among existing systems [6].

There are several policy and regulatory barriers that affect the development and deployment of technologies that can transform travel experience for the target user group. Policies that support universal design principles and data standardization can support development and implementation of applications that people of all abilities can benefit from. For example, several policy and regulatory barriers affect the outcome of services (e.g. paratransit service reservation within 24 h and service provision within a 2-h window) [7].

In summary, it was agreed that more awareness of disability needs and challenges along with universal design methodology be provided to AV designers and application developers. Policy and regulation should support development of infrastructure elements and development of advanced technologies and application that can bring transformative positive experience to the society.

3 Panel Discussion 2

The second panel focused on public policy and infrastructure related topics such as: standards harmonization, needs of other vulnerable road users, infrastructure needs, and public/private partnerships.

Increasingly, car manufacturers are seeking innovative ways to develop their businesses and are looking to provide mobility as part of their business model. Exploring such models call for an inclusive approach. Many people with disabilities do not have personal passenger vehicles, thus manufactures of AVs have much to gain by catering to this population. There was emphasis on the importance of standardizing data formats such as audio based data elements. Consistency in data formats would ease system integration and minimize technical differences. Harmonization of such standards across industries, regions and internationally can facilitate seamless travel experience for people of all abilities [8].

While all pedestrians may be considered vulnerable road users, pedestrians with disabilities face distinct and significant challenges when interacting with vehicular traffic. AVs may be able to accommodate and improve mobility for people with disabilities compared to current models, but it is equally important to consider how AV technology can improve safety for people with disabilities outside the vehicle. For example, what special requirements must AVs be designed around to enable detection of pedestrians with disabilities (for example, people in wheelchairs with guide dogs, or a blind person using a cane), and in what ways can AVs appropriately accommodate crossing needs of such individuals, for example holding the red signal longer to allow for additional time to cross? Bi-directional communication with AVs is important, especially during the transition phase where AVs and non-AVs are in the traffic mix, as well as when full transition occurs where all the vehicles in the traffic mix are AVs. Advanced methods of vehicle-pedestrian communication that allow for better handshake and synchronized communication between these systems should be encouraged. There are also concerns related to entry and egress of AVs such as automated passenger shuttles or automated taxis related both to vehicle design and policies such as pickup and drop-off locations. Finally, during development of these systems, the benefits of connectivity must be balanced with the knowledge that not all pedestrians will be connected to the AV ecosystem, which raises both technological and equity-related issues [9].

While developing AV design criteria for the target populations (people/veterans with disabilities, older adults), it is also critical to think about the interaction with the surrounding built environment as well. Without experience it is difficult to understand the real challenges people with disabilities face with insufficient infrastructure. Current data on infrastructure, such as location and conditions of sidewalks, is old and lacks the accessible details needed for AVs to make an impact. This can become a good business case for OEMs to explore. Some concerns related to transportation options currently available include: Inconvenient/inaccessible public & paratransit, limited Transportation Network Companies (TNCs) with accessible service, and interconnected elements of a trip such that if there is one system glitch, the whole trip goes down. As a result, there is need for new investments in understanding the needs of accessible transportation and the role of connectivity, smart infrastructure and related technology applications that would benefit travelers with disabilities [10].

One method to explore expanding the required infrastructure elements and characteristics is to leverage public and private partnerships. Public and private entities have different priorities; therefore, feel like they have different responsibilities to address only certain aspects of implementing AVs that is inclusive of all people. For example, public entities may have data on sidewalk conditions that can be complementary to high-definitions maps that AVs use to navigate. Such data sharing could help AVs recognize accessible sidewalk pick-up zones to accommodate, for example, people using wheelchairs. Budgetary constraints sometime prevent public agencies from meeting demand in a timely manner but could more effectively provide timely service by partnering with a TNC. With limited capital and human resources, and budgetary considerations, the capacity for service delivery of the paratransit agencies are constrained to meet increased/ growing demand. However, partnering with a TNC can help bring greater benefit to paratransit users. Another benefit of public-private partnership could include sharing of data in real-time. Availability and accuracy of reliable real-time data on malfunctioning equipment such as elevators, escalators, etc., construction activities and closures along paths to transit stations, bus stops, etc., or other types of disruptions along the trip route such as incidents, emergency evacuations, etc. is very important for trip completion. Sharing such data among agencies and adjacencies supporting mobility services can be beneficial to all parties involved [11].

4 Summary of Recommendations

Both panel discussions were stimulating and provided several insights for further consideration for the USDOT ATTRI program. Some of these recommendations are listed below.

- Integrate automation solutions in human service transportation for people with disabilities and older adults in both urban and rural areas
- The high-level travel needs of people with disabilities are the same as others such as getting to work, buying groceries, eating out, etc.; therefore, AV design must accommodate the varied challenges for complete inclusion and mobility for people with disabilities
- Data silos have limited value and it is critical to integrate various data sources into associated needs and services (e.g., connected citizens, care givers, safety alternatives)
- Technology is changing at a very rapid pace and different industries need to work together to develop integrated solutions while those solutions are in planning/design stages
- Making data sets available (construction, road/sidewalk roughness indices, etc.) and standardization of those data sets would help facilitate better integration and interoperability of technologies and applications for accessible transportation
- There is a need for new data (e.g., geo-location, dynamic, real-time) on infrastructure assets to analyze, plan, and support new investments
- The transportation industry needs to have collaborative efforts to review, analyze, and develop or make recommendations for updated sets of standards, policies, and regulatory frameworks for universal accessibility.

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External Vehicle Interfaces for Communication with Other Road Users?

Azra Habibovic, Jonas Andersson, Victor Malmsten Lundgren, Maria Klingegård, Cristofer Englund and Sofia Larsson

Abstract How to ensure trust and societal acceptance of automated vehicles (AVs) is a widely-discussed topic today. While trust and acceptance could be influenced by a range of factors, one thing is sure: the ability of AVs to safely and smoothly interact with other road users will play a key role. Based on our experiences from a series of studies, this paper elaborates on issues that AVs may face in interactions with other road users and whether external vehicle interfaces could support these interactions. Our overall conclusion is that such interfaces may be beneficial in situations where negotiation is needed. However, these benefits, and potential drawbacks, need to be further explored to create a common language, or standard, for how AVs should communicate with other road users.

Keywords External signaling · Communication of intent · Automated vehicles Other road users

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1 Introduction

In 1983, Bainbridge wrote in her paper on automation of industrial processes that "*[…] the irony that one is not by automating necessarily removing the difficulties, and also the possibility that resolving them will require even greater technological ingenuity than does classic automation.*" [1]. This is indeed highly applicable to automated vehicles (AVs) that are about to enter our society. As we change the human role in traffic, new challenges emerge.

By replacing human drivers, in some or in all driving situations, AVs are expected to eliminate issues related to human drivers. Large-scale introduction of such vehicles is thus anticipated to bring many benefits to the society, including improved safety, reduced congestion, lower emissions, higher productivity, and greater access to mobility. However, to reach these benefits, AVs will need to be trusted and to gain societal acceptance. While trust and acceptance could be affected by a range of factors [2], one thing is for sure: the ability of AVs to safely and smoothly interact with other road users in their vicinity will play a key role. That is, future AVs may face issues related to interaction with drivers of conventional vehicles as well as with vulnerable road users such as bicyclists and pedestrians.

When encountering a vehicle today, road users use both vehicle-centric cues such as velocity and deceleration, as well as driver-centric cues like eye contact, posture and gesture to interpret the traffic situation. With the transfer of control from the human driver to the vehicle, they will no longer be able to rely on the driver-centric cues, as the behavior of the person behind the steering wheel does not necessarily reflect the intentions and actions of the vehicle.

Currently, the research on interactions between AVs and other road users points in two directions: one advocating that motion patterns of AVs are sufficient to communicate the intent of AVs, and the other one suggesting that interactions will be affected by the lack of explicit communication with drivers and that external interfaces placed on AVs could be used to address this issue.

Based on our aggregated experiences from a series of studies, we elaborate in this paper on issues that AVs may face in mixed traffic environments and how these issues may be addressed by means of external vehicle interfaces.

2 Methodology

This paper is based on authors' aggregated knowledge gained from a series of studies on interactions between AVs and other road users, as well as the role of external vehicle interfaces in these interactions [3–7]. These studies are conducted in Sweden by RISE, Autoliv, Volvo Cars, Volvo Group, Scania, Viscando, Semcon, Halmstad University, SAFER, and AstaZero.

The elaboration presented here is built upon two use cases: (1) interaction between AVs and pedestrians, and (2) interaction between AVs and drivers of

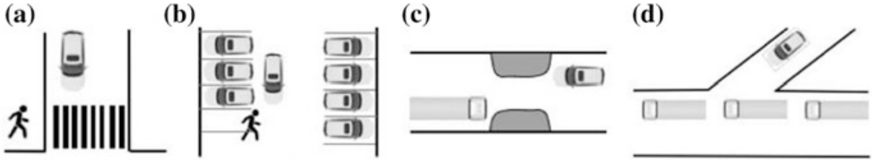

Fig. 1 Interactions between AVs and other road users are explored in four scenarios: **a** zebra crossing, **b** parking lot, **c** narrowed road, and **d** highway ramp

conventional vehicles. For each of the use cases, we describe current interactions and how these may change with the introduction of AVs, and how external vehicle interfaces may address potential issues. Each topic is exemplified by two traffic scenarios (Fig. 1):

(a) *A pedestrian encounters an automated passenger vehicle or a truck at a zebra crossing*. This scenario was investigated in a study at the test track AstaZero in Sweden with the aim to explore pedestrians' perceived safety and situation assessment, and to shed light on the role of an external vehicle interface called AVIP (see Sect. 3). The study involved 20 participants whose task was to act both as pedestrians and as a driver of a conventional passenger vehicle. Each test participant encountered one passenger vehicle and a truck at a time. In all encounters, the vehicle was operated by a human driver. While this was obvious in some of the encounters, in others the vehicle was seemingly operated either by automation without the AVIP-interface activated, or by automation with the AVIP-interface activated. That is, the study applied a 'Wizard of Oz' approach where the vehicle seems to be operated by automation, but is in fact operated by a human driver. All encounters were experienced at least twice and in a random order. For each pedestrian-vehicle encounter, the participants were asked to assess their perceived safety on a 7-point Likert scale. After completing all encounters, they filled in a questionnaire and participated in a semi-structured interview.

(b) *A pedestrian encounters an automated passenger vehicle at a parking lot*. The experiment was carried out in a public parking garage in Gothenburg, Sweden. The aim was to study pedestrians' self-assessed perceived safety in a traffic situation with unclear traffic regulations, and to explore the role of the AVIP external vehicle interface. The pedestrians encountered a conventional vehicle, a (seemingly) automated vehicle without the AVIP-interface, and a (seemingly) automated vehicle with the AVIP-interface in a random order. The encounters were repeated to eliminate first-encounter effects, and the pedestrians got also a short training on the interface. After each encounter the pedestrians rated their perceived safety on a 5-point Likert scale. At the end, they participated in a semi-structured interview.

(c) *A conventional passenger vehicle encounters an automated passenger vehicle or a truck at a symmetrically narrowed road*. See the description of scenario (a). Instead of assessing their perceived safety, the participants were asked to assess their interpretation of the traffic situation.

(d) *A conventional passenger vehicle encounters a platoon of automated trucks on a highway*. To explore the needs of external signaling for truck platoons, various highway scenarios (on-ramp, off-ramp, etc.) were used as a starting-point for a series of workshop discussions and interviews involving truck drivers with platooning experience as well as passenger vehicle drivers, OEMs and other experts in the field.

The basic principles of the external vehicle interface suggested by RISE and partners that was used to study interactions in these scenarios is described in the following section, followed by a walk-through the use cases.

3 A Minimalistic External Interface: AVIP

Inspired by the research in human-robot interaction where it is shown that revealing intentionality of robots makes them more predictable and generally more appealing to humans (see e.g., [8–10]), RISE and partners have designed an example interface concept named *AVIP: Automated Vehicle Interaction Principles* to enable practical studies of intent communication. It is guided by the idea of a minimalistic, generic and inexpensive design that could fit any vehicle independently of the brand.

AVIP consists of an outward-facing LED light strip that uses distinct patterns of light to inform surrounding road users about the state of the AV (on/off) and what the AV is about to do, without explicitly telling them what they should do and when (Fig. 2). We believe that inviting other road users to act may create false expectations of the surrounding traffic, which the AVs cannot necessarily account for. Instead, a design principle based on communicating intent rather than explicitly inviting people to act could avoid ambiguities. The placement of the AVIP signal used in scenarios (a)–(c) is illustrated in Fig. 2, while its placement in scenario (d) is illustrated in Fig. 3.

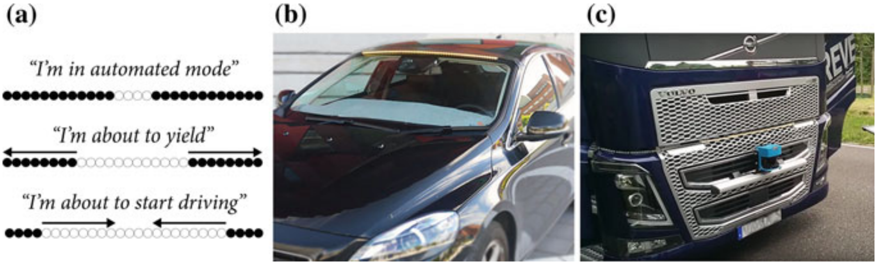

Fig. 2 The AVIP interface is dynamic (**a**). In passenger vehicles, it is placed on the top of the windshield (**b**); in trucks, it is placed in the middle of the grille (**c**)

Fig. 3 The AVIP concept of communicating intent in the platooning scenario

4 Use Case 1: Interaction Between AVs and Pedestrians

4.1 Current Interactions

If road users involved in an interaction do not have a similar understanding of the traffic situation, breakdowns in the interaction are likely to occur [11]. How pedestrians and vehicles interact is, however, still not fully defined. It is known that these interactions are complex and often affected by various external, internal and situational factors [12–18]. When there are ambiguities and negotiation is needed, road users use also nonverbal communication to clarify their intentions. Sucha and co-authors [18] found that pedestrians’ decisions to cross and feeling of safety are affected by various signals given by the driver such as eye contact, waving a hand, posture, and flashing lights. Schmidt and Färber [19] found that pedestrians who want to cross the street look at the approaching driver to get “acknowledgment”. Studies show also that nonverbal signals from pedestrians influence drivers’ behavior in terms of, for instance, increased yielding frequency [20–23], and increased time to collision and decreased severe braking by drivers [24]. On the other hand, Dey and Terken [25] found that pedestrians only resort to explicit communication when the vehicle’s expected behavior has been violated and that vehicle motion pattern plays a prominent role.

Altogether, this shows that nonverbal communication is an important, yet relatively understudied, aspect of safe interactions in the traffic system.

4.2 Interactions with AVs

Interactions between AVs and pedestrians are largely unexplored, but some examples exist. A recent study by Rothenbücher and co-authors [26], showed that pedestrians generally adhered to existing interaction patterns with vehicles unless the vehicle was behaving recklessly (e.g., decelerating late). Further, in a study by Dey and co-authors [27] it was found that distance and speed play a dominant role in the interaction between automated cars and pedestrians. Our own study, on the other hand, suggests that AV's may lead to a notable change in interaction patterns compared to conventional vehicles [3, 4]. The pedestrian participants rated eye contact with the driver as promoting calm interaction, while apparent driver distraction (e.g., talking on the phone, reading newspaper) led to pedestrian stress and ratings indicating an unpleasant interaction. They also implied that knowing the mode of the vehicle would allow them to align their expectations. Similarly, knowing the intentions of the vehicle would eliminate possible ambiguities due to the lack of communication with the "driver". Similar conclusions were presented in [28] and [29] where interactions between fully automated shuttles and pedestrians were investigated in real-world traffic and using virtual reality, respectively.

Based on these somewhat contradictory findings, it is possible that interactions between pedestrians and AVs are ambiguous due to both the lack of nonverbal communication with drivers, and the difference in the motion patterns. With the transfer of control from the driver to the vehicle, pedestrians will not be able to rely on cues in driver behavior anymore [30]. This could, in turn, lead to misinterpretation of an AV's intent and increase the risk of unpleasant encounters.

4.3 The Role of External Interfaces

To explore effects of the proposed AVIP external vehicle interface, evaluations were carried in two scenarios: at a zebra crossing (with clear traffic regulations) and a parking lot (with somewhat unclear traffic regulations), see Fig. 1a, b. After a short period of training, the majority of pedestrians were able to successfully interpret the AVIP's signals. Findings also indicated pedestrians may benefit in terms of comfort and perceived safety from knowing the mode and intent of AVs. In both scenarios, the level of perceived safety was similar in encounters with conventional vehicles and in counters with AVs with AVIP, while the encounters with the AVs without AVIP resulted in a lower perceived safety. Interestingly, the pedestrians' ratings of safety did not differ between passenger vehicles and trucks, nor between the two places. The pedestrians also stated that the AVIP increased their trust in AVs and that future AVs should be equipped with this, or a similar, interface.

While our results indicate that an minimalistic and generic external vehicle interface such as AVIP could have positive impact on interactions between AVs and pedestrians, there are other studies implying that such a support will not be needed [26, 31, 32], which shows the complexity of the topic, and calls for more research on the role of external interfaces.

4.4 Potential Challenges

A potential challenge that we identified in our studies is how to ensure that pedestrians can interpret the signals displayed by an external vehicle interfaces. This could be especially challenging in the early introduction phase of AVs. At the same time, external vehicle interfaces may be the most valuable when AVs are new to pedestrians to boost the acceptance and help developing proper mental models about behaviors of such vehicles.

Another potential challenge is how external vehicle interfaces will function in a multi-agent scenario. Our research indicates that the signals should be simple and not too many, but is it possible to develop a few signals that are enough to convey an AV's intentions in a complex mixed traffic environment? Variations in cultural norms as well as age and gender related differences among pedestrians may add an additional dimension to this challenge.

It is also difficult today to anticipate if the use of external interfaces would result in (negative) secondary effects. Could it, for instance, lead to a shorter gap acceptance by pedestrians? In a long-term perspective, it is also likely that such interfaces could contribute to information overload, which in turn could affect behavior of pedestrians and overall traffic safety.

5 Use Case 2: Interaction Between AVs and Drivers of Conventional Vehicles

5.1 Current Interactions

The inter-vehicle interactions are today affected mainly by traffic regulations. However, in some situations the regulations are unclear and drivers express own, and interpret other drivers', intentions using various nonverbal cues such as vehicle placement, velocity and deceleration, signaling devices such as blinkers, honk, headlight flashing, and brake lights, eye contact and hand gestures [33, 34]. Understanding inter-vehicle interactions requires thus an understanding of nonverbal communication aspects [35, 36]. The meaning of nonverbal cues are, however, uncertain and vary depending on various factors including traffic situation (e.g., distance, time pressure), driver age, gender, mental state, expectations and culture [37–40]. As a rule of thumb, if the distance is larger, the drivers tend to rely on vehicle-centric cues. If distances are shorter, the drivers start relying more on driver-centric cues [36].

5.2 Interactions with AVs

Although evaluations of AVs in mixed traffic are common in some areas, researchers still lack an in-depth understanding of how these vehicles interact with drivers of conventional vehicles, and what challenges they face. In their study on effects of nonverbal communication, Kitazaki and Myhre [33] conclude that traffic safety and efficiency as well as trust towards AVs may be enhanced if AVs are able to communicate information on their state and information that "replaces" driver-centric cues such as hand gestures.

During projects on platooning in real traffic e.g., European Truck Platooning Challenge [41], trucks equipped with wireless communication drove in platoons through Europe from Sweden, Germany, Belgium to Rotterdam in the Netherlands. During this event, it became clear that in heavy traffic, the truck drivers experience that the surrounding traffic performs risky maneuvers as they cut in between trucks that are driving in the platoon. In the platoon scenario, the cut ins from the surrounding traffic do not only impinge the traffic safety, they also reduce the fuel saving that is obtained by the reduced wind drag enabled by the short inter-vehicular distance.

5.3 The Role of External Interfaces

The results from the evaluations in the narrow road scenario (c) indicate that the AVIP interface could ease situation assessment in encounters between conventional and AVs where formal rules are missing and mutual negotiation is needed. It was also noticed that the drivers of conventional vehicles considered such an interface more useful in encounters with passenger vehicles, rather than in encounters with trucks. This since they could easily anticipate/accept that trucks get priority in such situations due to their size. It was also suggested that external vehicle interfaces may be useful in solving ambiguities that drivers face today in unclear traffic situations.

For trucks involved in a platoon, the rationale of external signaling is to inform other road users in the vicinity that platooning is ongoing, and that the trucks wish to stay together without interruption. Our studies in scenario (d) indicate that the most relevant situations for external signaling for platoons are highways at on-ramps, off-ramps, during overtaking, and lane changes. According to workshops and interviews with Swedish truck drivers these are situations where a platoon is most likely to experience a cut-in and could benefit the most from communicating its intention to stay together as a group [6]. The frequency of cut-ins clearly depends also on other factors than just external signaling, e.g. traffic density, vehicle distance, number of vehicles in the platoon, infrastructure, etc., and it is difficult to judge the reduction of cut-ins solely due to external signaling without trials in realistic traffic situations. However, the external signaling could also have a positive effect on the acceptance and understanding of platoon behavior, since encountering a "train" of heavy trucks could be perceived as intimidating by other road users.

5.4 Potential Challenges

The challenges highlighted in Sect. 4.4 are largely applicable here as well. In the platooning use case, a barrier to implement external signaling on the trailer is the fact that trailers are often switched between different haulers. It will be unclear who should cover the cost for the installation and maintenance of the signaling system on the trailers. The possibility of using existing positioning lights should be explored. The fact that trailers are constantly rotating between different tractors may be a significant barrier for wide implementation of visual communication for trucks that should communicate their intentions while driving in a platoon. This may require that trailers rather than tractors need to be equipped with communication devices. Another challenge is to understand the value of providing information to the surrounding traffic in terms of their perceived safety and comfort when interacting with truck platoons. Is it possible to perform the transformation of perceived safety and comfort to a value comparable to loss or gain of fuel savings?

6 Discussion and Conclusions

Altogether, our results indicate that communication needs may change when AVs are introduced in the traffic system, and that other road users may gain in terms of comfort and perceived safety from knowing the mode and intent of AVs. This is in line with other studies from human-robot interaction suggesting that mutual understanding of each other's intent is crucial for safe and pleasant interactions. A way to facilitate mutual understanding is therefore to clearly communicate own intent to other road users in the vicinity.

The initial evaluations of AVIP in the scenarios described previously (a–d) indicate that it could potentially lead to a higher level of perceived safety and improved energy efficiency (e.g., platoon splits due to cut-ins by other road users at highway ramps may be avoided). On the other hand, in some situations in the current traffic, road users interpret a conventional vehicle's intention without any nonverbal communication with the driver (e.g., in darkness where we cannot see the driver's face or gestures). As argued by some contemporary studies (e.g., [26, 27, 32]), the intent of AVs could perhaps be sufficiently communicated based on motion patterns only. Still, our results indicate that communicating the intent of the AV using an external interface can contribute to a positive interaction experience. Learned positive experiences are important for building trust and acceptance towards new technologies [42]. Recent surveys show that people are currently largely sceptic towards AVs [43], and if an AV can give other road users a feeling of trust and provide a joint understanding of what is about to happen, this should be a strong advantage for any AV-manufacturer.

At the same time, the development of external vehicle interfaces call for harmonization, or even standardization. To avoid confusion, it is necessary that such communication is unified across different vehicle types and brands. However, the questions what should be unified, and to what extent, remain. One design principle that we applied for the AVIP, and that we believe should be adopted independently of the interface implementation, is to communicate intent rather than explicitly invite people to act. This to avoid possible ambiguities due to a mismatch between the vehicle's invitation and the surrounding traffic [7].

Despite our, and other researchers', work on interactions with AVs and the role of external vehicle interfaces, it is at the moment largely unknown how other road users will behave around these vehicles and what behaviors they will adapt over time. An important aspect is how sensitive an AV need, and should, be to the appearance and behavior of other road users, and to what extent it should adapt any possible external interface accordingly. Still, what is important to remember is that by introducing means for people to better interpret and understand these vehicles it will add to shape the way they are interacted with and accepted.

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Part III
Technology, Energy and Business Perspectives

Assessing Energy Impacts of Connected and Automated Vehicles at the U.S. National Level—Preliminary Bounds and Proposed Methods

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Abstract Connected and automated vehicles (CAVs) can have tremendous impacts on transportation energy use. Using published literature to establish bounds for factors impacting vehicle demand and vehicle efficiency, we find that CAVs can potentially lead to a threefold increase *or* decrease in light-duty vehicle energy consumption in the United States. Much of this uncertainty is due to possible changes in travel patterns (in vehicle miles traveled) or fuel efficiency (in gallons per mile), as well as future adoption levels and patterns of use. This chapter details the factors which go into these estimates, and presents a methodological approach for refining this wide range of estimated fuel consumption.

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1 Bounds on Energy Consumption of Connected and Automated Vehicles in the United States

The range of potential impacts of connected and automated vehicles (CAVs) on energy use by the U.S. transportation sector is large and highly uncertain. Upper and lower bounds of these energy impacts for light-duty vehicles (LDVs) in the United States were recently estimated from a synthesis of relevant studies and available data [1]. Estimated impacts were synthesized into three CAVs scenarios: Partial (corresponding to SAE levels 1 or 2 [2], with limited connectivity), Full-No Rideshare (corresponding to full automation, SAE levels 4 or 5 [2], with high connectivity between vehicles and with traffic infrastructure) and Full-With Rideshare (full automation with high connectivity and ridesharing). The efficiency calculations relied on literature-reported values for different CAV feature impacts on fuel consumption rates (e.g., due to vehicle-to-infrastructure communication/coordination, vehicle platooning, etc.), and also include a first-order disaggregation of each feature's impact in different driving situations (i.e., city vs. highway driving and travel at peak vs. off-peak times). The relative impacts were then weighted by the amount of driving that takes place in those different situations. The calculations of impact on vehicle miles traveled (VMT) included vehicle occupancy assumptions to translate between person miles traveled (PMT) and VMT.

Generally, the factors that impact total energy usage can be grouped into three categories: those that influence (1) vehicle fuel consumption per mile, (2) travel demand, or VMT, and (3) CAV adoption. Six factors for fuel efficiency and six factors for travel demand were examined, while assuming instantaneous, near-ubiquitous coverage of CAVs. The upper bound estimates for each scenario

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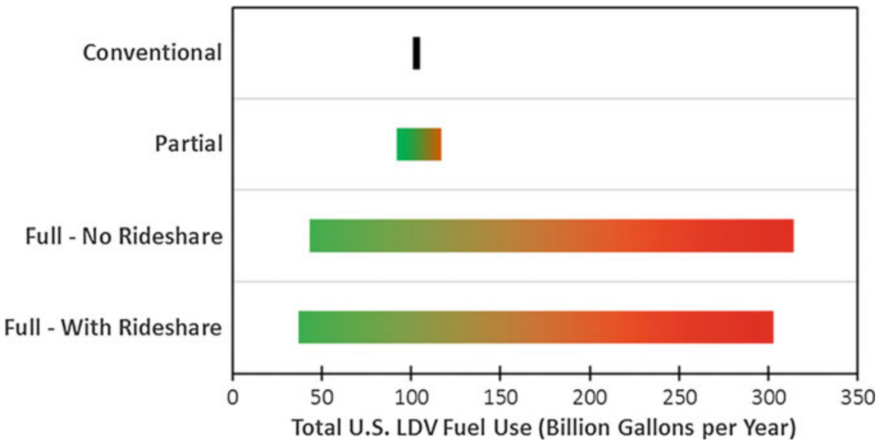

Fig. 1 Potential energy impacts of varying levels of vehicle automation (adapted from [1])

assume maximally energy increasing combinations of CAV effects on VMT and vehicle efficiency (i.e., many more miles traveled with little or no fuel economy gains), whereas the lower bound estimates assume small increases (or decreases) in VMT along with more aggressive vehicle efficiency improvements. The results (summarized in Fig. 1) illustrate wide separation between the scenarios' upper and lower bounds on U.S. LDV fuel use, reflecting the large uncertainties in the impacts of CAVs on both vehicle fuel consumption rates and VMT. The upper bound for the Full-No Rideshare scenario represents the highest increasing fuel use case, tripling the annual fuel use of the base scenario. The lower bound of the "Full-With Rideshare" scenario represents the lowest decreasing fuel use case with less than 40% of the base scenario's fuel use. In contrast, the partial automation scenario shows a much more modest range of impacts, on the order of ±10% for the upper and lower bounds relative to the base scenario.

Factors influencing vehicle efficiency that were considered here include: vehicle right-sizing, smoother driving, platooning, and faster (safe) travel, collision avoidance (resulting is less congestion), and intersection vehicle-to-infrastructure (V2I) connectivity. Right-sizing (under a wide range assumed for the potential reduction of vehicle mass) gives the largest potential efficiency increase. Improved driving efficiency from smoother driving, platooning, and connectivity offer potential reductions in fuel consumption as well. Faster (safe) travel can potentially increase fuel consumption. Most of the CAV factors considered can potentially decrease fuel consumption per mile with the exception of higher speed travel. Note that an increase in fuel consumption due to larger CAVs was not considered since that was not mentioned in the literature reviewed, but an increase in average vehicle size associated with CAVs could be possible.

Factors that potentially influence travel demand by LDVs (as indicated by VMT) included easier travel (due to a lower perceived cost of travel time), increased travel by underserved persons, empty vehicle miles traveled (by driverless vehicles being

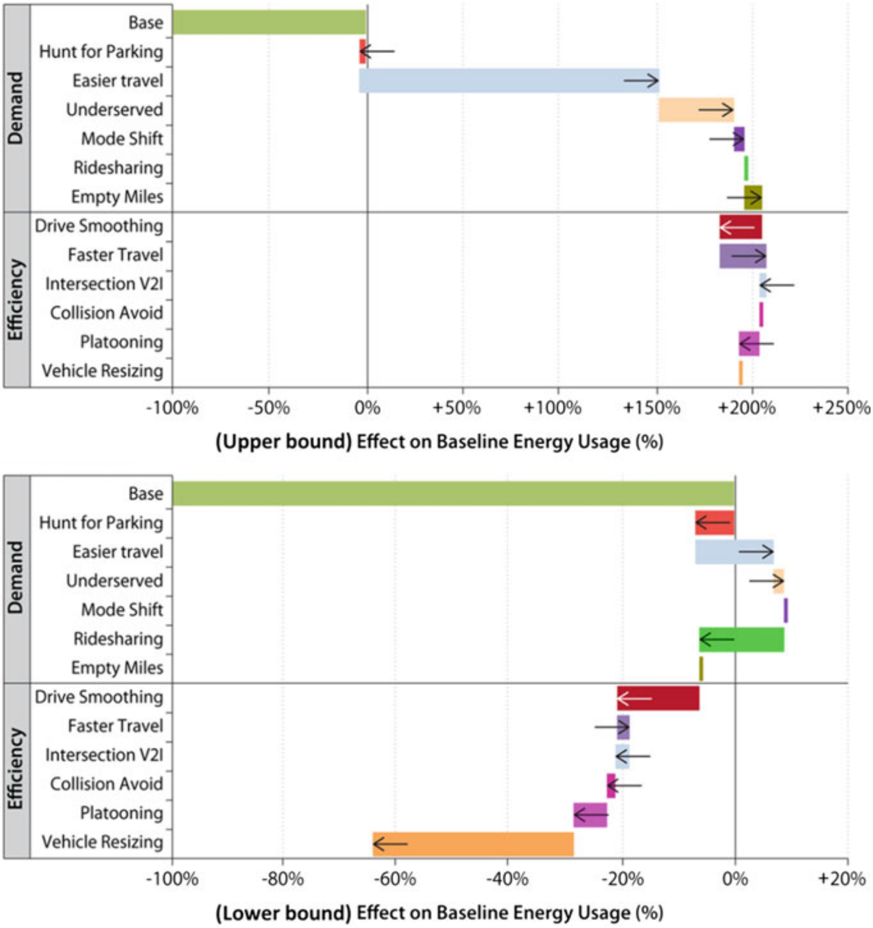

Fig. 2 Upper and lower bounds of the influence of each factor on total fuel use, assuming full autonomy (adapted from [1])

repositioned), changes in ridesharing, and shift from other travel models to CAVs. The potential influence of CAVs on travel demand is quite large with possible increases due to easier travel being the largest component. Repositioning of empty CAVs could increase VMT, but few estimates of this increase were found in literature, and these estimates were small (a few percent). Increased ridesharing could decrease VMT, but adoption of ridesharing is very uncertain.[1]

Figure 2 highlights the most important factors influencing the upper and lower bounds on fuel use. For the upper bound cases, large VMT changes due to easier

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[1] Ridesharing refers to a net increase in vehicle occupancy resulting from two or more people riding together in a vehicle during some or all of their travel.

travel (faster travel and reduced travel time cost) serve as the largest potential driver on increasing fuel consumption, with empty travel by driverless CAVs and increased fuel consumption per mile due to high-speed travel representing the next most influential factors. In the lowest energy scenario, decreased fuel use is largely due to aggressive vehicle and powertrain downsizing, combined with smoother driving and a modest decrease in VMT due to ridesharing.

The wide range between the lower and upper bounds on future vehicle energy use reflects the large uncertainties in ways that CAVs can potentially influence vehicle efficiency and use through changes in vehicle design, driving, and travel behavior. In addition, significant future CAV technology adoption rates are very uncertain. Use of alternative powertrain technologies such as electric drive is likely to reduce both the upper and lower bounds on fuel consumption for the examined scenarios. However, the relative impact of different CAV features in advanced powertrains is expected to differ from that in conventional vehicles, so future work will explore the combined impacts of advanced powertrain and CAV technologies.

The bounding analysis above assumes an instantaneous introduction of CAVs to the national light-duty vehicle fleet. Building on the methodology described above, the Energy Information Administration (EIA) contracted a report to examine how CAVs technologies might be introduced to the fleet [3], to prepare for future inclusion in the Annual Energy Outlook (AEO). This report shows less than 10% variation in national-scale fuel consumption relative to the reference case due to light-duty CAVs by 2035, but impacts reach potentially as much as ±50% by 2050 due to fleet turnover.

2 Transferability of Bounds on Energy Consumption of Connected and Automated Vehicles in the United States

2.1 Transferring Detailed Simulations to the National Level

While a number of efforts are underway to model and analyze future travel behavior and transportation energy use in CAVs deployment scenarios, these simulations are mostly limited in geographic scope. For example, a team from Argonne National Laboratory simulated travel throughout the Chicago metropolitan area with a fraction of vehicles equipped with cooperative adaptive cruise control (CACC) which was assumed to increase highway capacity, depending on the fraction of vehicles with CACC [4]. Using an activity-based transportation simulation model in POLARIS, they found that the increased capacity from vehicle automation and connectivity induced additional trips modestly (a percent, depending on conditions assumed), but reduced value of travel time (VOTT, assumed to result from vehicle automation) induced significant additional travel. Childress et al. [5] simulated travel in the Puget Sound region and also found that increased capacity and reduced VOTT increased travel demand.

Such detailed simulations, particularly those using activity-based models capable of modeling changes in travel behavior, are valuable in estimating changes in travel and vehicle use, but are necessarily limited by complexity and data requirements to regional areas and cannot be used to simulate travel at a national scale. Therefore, transferability modeling is being adopted to take results from regional simulations of CAVs to estimate changes in travel demand at the national level [6]. Transferable variables such as total daily trip rates (number of trips per day) and travel times for each individual are derived from POLARIS simulation results for CAV scenarios. A two-step clustering algorithm is then used to assign people into homogeneous groups through which various types of lifestyles are captured, followed by estimating joint models of number of daily trips and total travel time within each cluster. Finally, using an artificial neural network model, cluster membership rules are transferred to the national level data and the estimated joint models are simulated within the corresponding clusters. Comparison of distributions of transferred variables in the regional and national contexts for current conditions (no CAVs) indicate that the platform is capable of transferring travel behavior to the national level with a high level of accuracy. For transferring number of daily trips and total daily travel time, ten clusters were identified and distributions of these travel metrics were estimated. For validation, these distributions were compared with distributions for the national-level households assigned to the clusters identified in the regional data. Figure 3, for example, compares the transferred distribution of trip rate with the observed distribution for one of the population clusters. This shows good agreement, typical of the other clusters. This validation adds confidence in the transfer modeling, but further validation is planned which will compare results from POLARIS simulations of cooperative adaptive cruise control in southeastern Michigan with results transferred from POLARIS simulations of CACC deployed in the Chicago region.

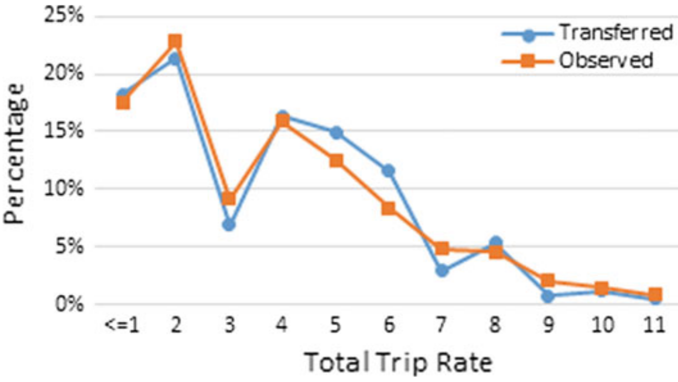

Fig. 3 Comparison of observed and transferred daily trip rates for a sample population cluster

2.2 Aggregating Energy and Greenhouse Gas Impacts of CAVs Nationally

A framework that accounts for energy impacts at the vehicle level, projected adoption levels, and changes in VMT has been developed to estimate national level fuel consumption impacts of CAVs [7]. Vehicle fuel consumption is calculated as the product of VMT and fuel consumption in gallons per mile. The model accounts for the fleet evolution with a vehicle stock and usage model, which attempts to match the model structure and time period (2015–2050) of the 2017 Annual Energy Outlook [8]. Disaggregated data on annual miles traveled and fuel efficiency of each trip by model year and vintage year are also integrated with the stock model. In addition, this data-rich approach accounts for the average daily traffic volume, VMT, average speed, and road type on each road link of the U.S. transportation system.

Initially focusing on passenger travel in light-duty vehicles, the framework accounts for technological progress in CAVs and non-CAVs in the fleet to reflect potential spatial and temporal energy impacts of such technologies. It allows exploring national-level scenarios with transparent and consistent assumptions. Information flows in the framework are shown in Fig. 4.

To exercise the framework, initial placeholder assumptions were used for future CAVs adoption levels, on-road fleet mix of powertrain types, VMT changes, vehicle-level fuel economy impacts, and other inputs [9].[2] Figure 5 shows the total gasoline consumption projections from 2017 to 2050, which are outcomes of several scenarios: Base-AEO (based on AEO 2017 Reference case), Base-ADOPT (based on AEO 2017 inputs with projected vehicle sales shares from ADOPT) CACC-AEO (with CACC penetration projections applied to the Base-AEO case), CACC-ADOPT (with CACC applied to the Base-ADOPT case), AutoTaxi-AEO (with automated taxis penetration projections applied to the Base-AEO case) and AutoTaxi-ADOPT (with automated taxis applied to the Base-ADOPT case).

Findings in Fig. 5 compare gasoline fuel consumption from the various CAVs scenarios with comparable estimates, assuming that CAVs technologies fail to penetrate the market (BASE cases), and highlight the impacts of particularly influential input assumptions in the analysis. These example results attest to the functionality of the framework and should not to be interpreted as predictions. For example, the CACC scenario assumptions lead to increased fuel consumption projections due to overall VMT increase and certain VMT percentage shifts to higher speed bins (due to CACC smoothing driving profiles). Differences between the two baseline projections, more specifically BASE-AEO and BASE-ADOPT, show the importance of baseline vehicle sales on estimating fuel consumption to permit meaningful scenario comparison. These initial demonstrations showcase the capability of the developed national-level framework to utilize disaggregated data

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[2] Inputs regarding powertrain adoption projections stem from EIA's AEO and NREL's Automotive Deployment Options Projection Tool (ADOPT) [10].

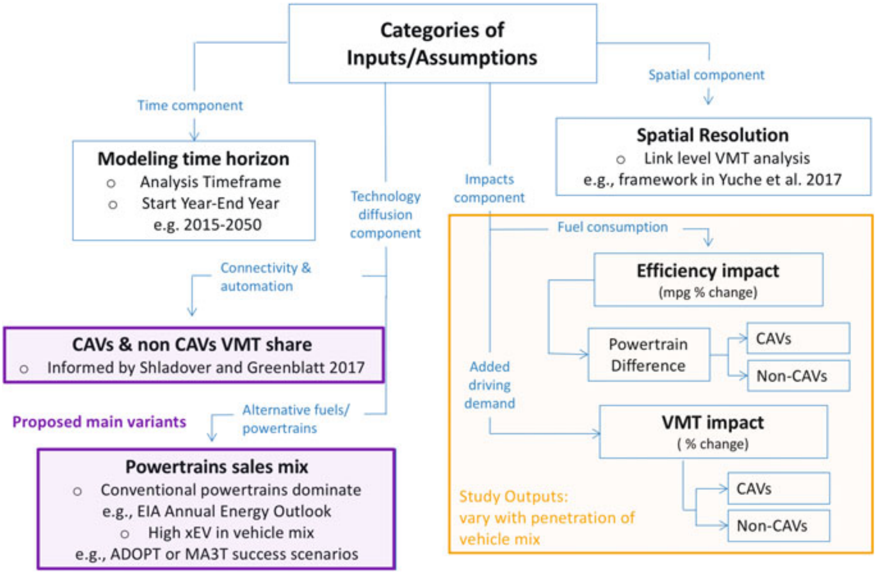

Fig. 4 Assumptions and inputs utilized in the national-level modeling framework

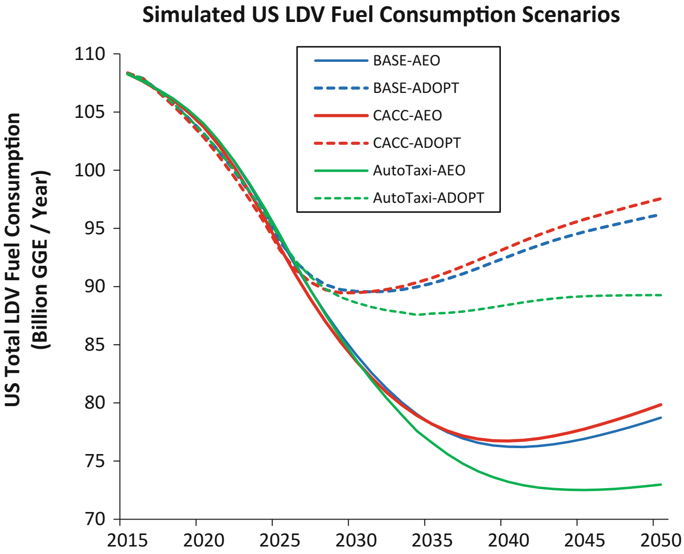

Fig. 5 Simulated U.S. light-duty vehicle fuel consumption scenarios

on vehicle miles traveled per road type, fuel economy by speed, vehicle age and its relationship to fuel economy, to estimate aggregate fuel consumption impacts. More refined inputs will allow further exploration of energy impacts for differing CACC and AutoTaxi use cases, as well as additional CAVs technology scenarios.

2.3 Modeling Adoption of CAVs and Shared Mobility

To estimate possible adoption levels of CAVs as well as shared mobility services, the Market Acceptance of Advanced Automotive Technologies (MA^3T) model from Oak Ridge National Laboratory has been expanded to include choices of buying a CAV, use of shared mobility (either conventional vehicle or CAV) or use transit [11]. Figure 6 shows the expanded choice structure of the mobility choice module, and how the new options relate to the potential mobility ecosystems presented by the U.S. Department of Energy [12]. Preliminary results examine the projected sales shares by fuel type for human-driven and automated vehicles, projected sales shares by automation, and the impact of automation on vehicle ownership.

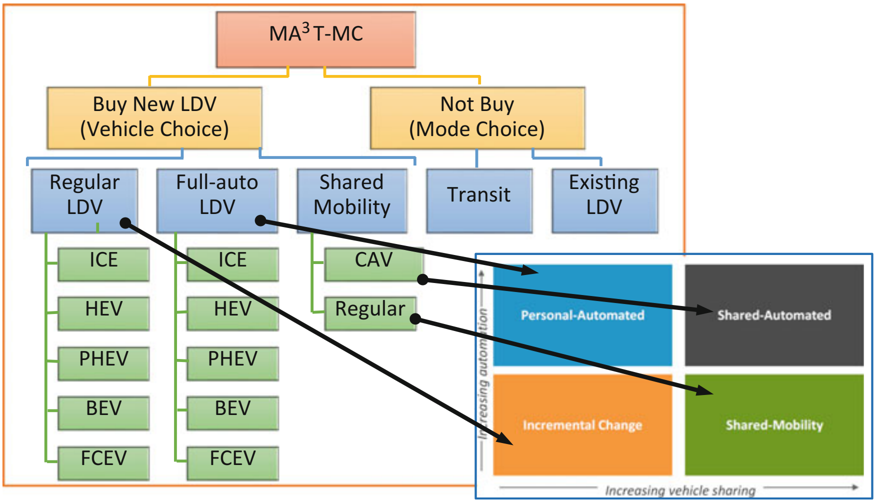

Fig. 6 Mobility choice module in the MA^3T model (adapted from [11])

3 Conclusions

CAVs can potentially decrease or increase highway energy usage, due to improved vehicle and system efficiency or increased travel demand, respectively. Specific areas requiring significant research and analysis to reduce uncertainties include assessing potential changes in travel demand due to CAVs, estimating future CAV adoption, analyzing potential effects on vehicle efficiency and redesign, and estimating future heavy-duty CAV energy impacts.

Methods to estimate potential adoption of CAVs technologies are being developed by extending the MA^3T model to capture new mobility choices made available through CAVs. Such estimates will be used in models of CAVs deployment at a regional or local level or will inform assumption made at the national level. Methods to expand vehicle-level and regional simulation and modeling results of CAVs are being developed and show good progress through the initial validation of the methods. Preliminary demonstration of aggregation methods shows the capability of the developed framework to estimate national-level LDV fuel consumption. As vehicle-level and regional-level results become available from related research, these methods will be refined and applied to deliver national-level energy impacts results for scenarios of interest.

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Deployment of Automated Driving as an Example for the San Francisco Bay Area

Sven A. Beiker

Abstract There is a lot of discussion about the different levels of vehicle automation and when respective products will come to the market. When taking a closer look, one actually observes that different experts often talk about different scenarios even when contemplating the same level of automation. In order to generate a more comprehensive perspective on the different levels of automation and their timelines for market deployment, this contribution analyses expert interviews and extensive media research. The picture that emerges from this spans a deployment roadmap from automated shuttle services launching still this decade to automated highway driving and delivery services some 20 years into the future. Hypothetical scenarios for the San Francisco Bay Area are provided as potential examples.

Keywords Automated driving · Autonomous driving · Deployment scenario
Automated shuttle · Truck automation · Platooning · Automated delivery
San Francisco Bay Area

1 Context and Scope

Without any doubt has automated driving become one of the most defining trends shaping the future of the automobile and with that the future of mobility and transportation. The general media, industry announcements, analyst reports, etc. continuously entertain this field and there is no shortage of forecasts as to when automated driving will come to the market [1–8]. The 2017 Automated Vehicle Symposium was no exception to this discussion and many presentations also included timelines for the deployment of respective automated driving concepts or

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products. When engaging in those discussions on deployment scenarios, one often observes contradiction, rejection, or misunderstanding in terms of the projected timelines.

Given this situation of high interest and at the same time much confusion, this contribution aims to summarize the discussion among experts and observers, to align with the many forecasts, and to integrate different perspectives in the field. Therefore publicly available information was analyzed for deployment timelines and expert interviews were conducted to inform a comprehensive deployment scenario. Many of those interviews were conducted at or around the 2017 Automated Vehicle Symposium, so that this determines the timeliness of the scenarios and this also creates a strong tie to the Symposium. As the list of references at the end of this contribution shows, almost 50 media articles and press announcements were analyzed to create this perspective.

The automated driving scenarios to be discussed in this contribution are supposed to cover a broad spectrum of directions. That is important to align the discussion in industry, regulation, and media as to which kind of automated vehicle will come to the market when and where. On can easily attest that the now broadly used levels of automation as established by SAE International [9] are very helpful to determine the kind of automation, and therefore they are also used throughout this publication as “L3, L4, L5”. However, they do not unambiguously determine what kind of vehicle and what kind of use case is referenced. Therefore the following scenarios and concepts will be discussed further in this contribution and an outlook for their public deployment will be made:

- Private passenger vehicles
- Shared passenger shuttles
- Long-haul trucks
- Local delivery vehicles.

2 Automated Driving Concepts to Be Differentiated

In order to map out deployment scenarios for automated driving, different concepts should be differentiated as they are characterized by distinct aspects and have different time horizons regarding their deployment in public. Therefore, before considering respective deployment scenarios, the different concepts will be discussed first one by one.

2.1 Private Passenger Vehicles

The automated private passenger vehicle is the most anticipated form of an automated vehicle, which means it is arguably most often talked-about in the technical

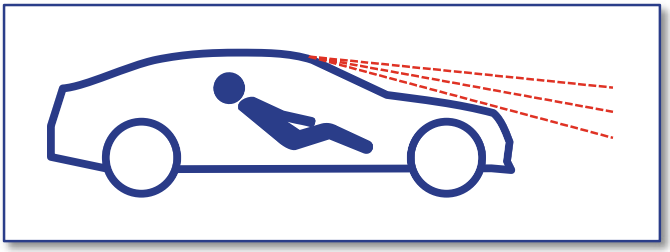


Fig. 1 Schematic depiction of an automated private passenger vehicle (red lines symbolize the automation concept, such as beams from a LiDAR system)

community and pubic media, and it is arguably the one that first comes to consumer minds when thinking about a "self-driving car". Figure 1 shows a schematic depiction of this concept, which is a privately used and typically also privately owned light duty vehicle that can drive without human interaction. The depiction even shows the often-discussed scenario that the driver becomes a passenger and does not need to engage in the driving process at all.

The established automotive industry pursues this scenario at large [10–12]. This is basically the evolution of today's passenger vehicles toward L5 automation, i.e. a vehicle that consumers own or lease for a certain number of years as their primary means of transportation, which can typically accommodate 4–7 people, and which can carry personal items such as shopping goods, leisure equipment or baggage. Thereby it is intended to cover many use cases from the daily commute and errands to occasional travel and leisure. The goal is to automate as many driving situations as possible, currently highway driving and parking are the furthest developed with L2 and L3 features available on the market [13–15].

The benefits of such an automated private passenger vehicle, which has been discussed in many publications, are improved safety, more productive transit time, and increased mobility [16–18]. In order to implement such technology, the industry is in need of high performance sensors for object detection, processing for situation classification and maneuver planning, and potentially a communication infrastructure that allows for a coordination of eventually driverless vehicles. Given the nature of those vehicles, i.e. a privately owned and unsupervised product, the automation concept needs to be highly reliable, low cost, and maintenance-free. As those requirements are relatively extreme, it can be expected that such automated private passenger vehicles will take a long time to reach full potential and therefore an evolutionary deployment scenario seems likely. Currently the first L3 systems are introduced to the market [14], L4 might be introduced within the next 5–10 years, and L5 should not be expected before 2030 [19, 20].

2.2 *Shared Passenger Shuttles*

Recently, the automated shared passenger shuttle has gotten much attention by corporations and also the media [21–23]. The idea here is a passenger vehicle specifically tailored to public usage in a pre-determined operating area (e.g. downtown of a particular city) and that is entirely intended for driverless operation.

Figure 2 shows such a concept as a schematic rendering, which makes the difference to the before described private passenger vehicle clear. While both are intended to transport people, the shuttle is a rather utilitarian vehicle that is optimized for short trips in an urban setting. And also, in contrast to the privately owned and operated vehicle, which can be taken to any destination on any route, an automated shared shuttle does not service any arbitrary route or destination, but only the ones pre-determined as the operating area (e.g. a certain downtown district but not the highway to the next city).

The benefits of such a mobility service are financial savings through the driverless operations as the labor cost for typical transportation solutions often amounts to up to 50% of the fee [24]. And as the overall cost for such a driverless operation is lower, a denser service network and freely scheduled operation can be realized. Thereby consumers take advantage of the flexibility known today from personal mobility and the low cost known today from public transportation.

The needs to implement such an automated shared passenger shuttle are similar to the private vehicle, which are respective sensors, processors, and infrastructure. However, since those shuttles will be operated by a professional entity (e.g. transportation network company) in a specific operating area (e.g. downtown districts), the operation can be planned and supervised. Therefore, early-stage systems can be deployed, which might be upgraded over lifetime and can be of higher per-unit cost because the anticipated high utilization enables faster amortization than in case of a privately owned vehicle. For those reasons, automated shared passenger shuttles might be deployed in public in the very short term, i.e. by the end of this decade. Pilot operations and announcements from tech companies support this projection [25–28]. Those announcements also document that, other than the traditional automotive companies, who primarily pursue the automation of the

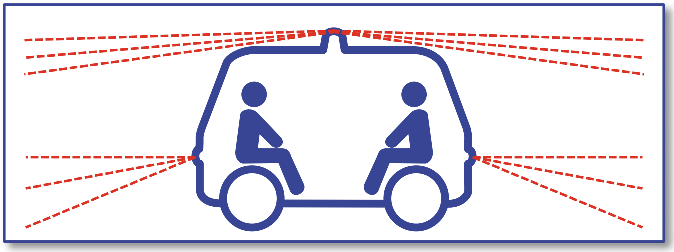


Fig. 2 Schematic depiction of an automated shared passenger shuttle (red lines symbolize the automation concept, such as beams from a LiDAR system)

private vehicle, it is the tech industry that aims for the automation of shared vehicles as a new service business. With this combination of new technology (automated vehicle), new business models (shared ownership/renting), and new operating modes (pre-determined service areas) this arrangement is a rather transformative shift in personal mobility while the traditional automotive manufacturers pursue a more evolutionary approach as discussed before.

2.3 Long-Haul Trucks

Trucks, especially the ones for long-haul operation, are another often-discussed topic in the field of vehicle automation. Established automotive players and startups alike pursue those concepts [29–34]. In this, a setting where two or more vehicles are tethered to one another via a virtual link plays a special role as the long distances on relatively predictable highways present a favorable situation. Such an automated platoon is also depicted in Fig. 3 as a special, and quite likely scenario for automated long-haul trucks. In contrast to a single automated vehicle, the platoon is, strictly speaking, not a completely automated vehicle as there would still be a human driver in the lead vehicle and only all following vehicles (concepts with up to eight vehicles total have been discussed) are driverless.

The benefit of an automated platoon is primarily the lower operating cost as the aerodynamic drag is reduced making fuel savings around 10% possible [35]. Additionally, safety can be increased as automatic steering and longitudinal control of the tethered vehicles is less prone to errors like lane departure or rear-ending, an imminent risk of human drivers due to inattention or fatigue.

In order to implement such platoons, on-board sensors and data communication between the vehicles is necessary, which basically exist today. In that regard, the major challenges for deployment are regulation and coordination to integrate such convoys of up to 8-vehicle lengths into existing traffic patterns. It can be expected that those hurdles will be overcome soon, especially as intensive testing has been

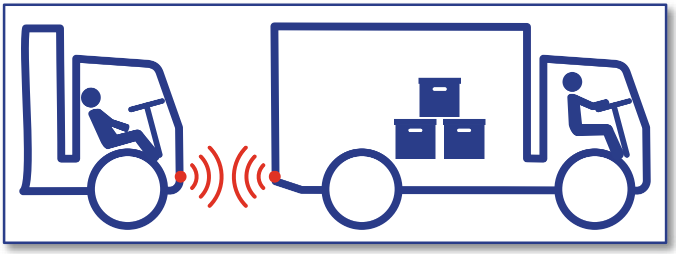


Fig. 3 Schematic depiction of an automated long-haul truck platoon (red lines symbolize the automation concept, such as WiFi communication between the vehicles)

undertaken for about 10 years now [33, 35] so that public deployment might happen early in the next decade.

In addition to such platoons, other concepts for automated long-haul trucks target specifically highway operation as well. Those focus however on single vehicle operation with special assistance to get the vehicles with human interaction onto and off the highway [34]. Such examples could be that a human is on the vehicle for on- and off-ramp driving but can perform other tasks while on highway, or a human can tele-operate the on- and off-ramp situations so that one operator can drive many more vehicles than in today's setting where one driver is assigned to exactly one truck for the entire journey. Either way, the motivation is to increase productivity or to reduce operating cost. However, those concepts might take longer to implement in public because of their higher complexity.

2.4 Local Delivery Vehicles

Another automation concept that focuses specifically on the transportation of goods is the automated local delivery vehicle. Figure 4 depicts schematically such a concept that is basically a driverless version of the van typically used by delivery companies like the postal or courier services.

Other types can easily be envisioned such as small automated ground vehicles like delivery robots or even flying automated areal vehicles like drones. All of those are actively be pursued, in particular by said delivery services and tech companies [36, 37].

The benefit of such automated delivery vehicles is again a lower cost structure as human operation or supervision is not necessary. The reason is that the last mile delivery accounts for about 50% of the cost in the logistics chain because humans need to spend time driving from the local distribution center (LDC) to the delivery area, then find the exact address, take the shipment from the vehicle, deliver it to the recipient, and confirm delivery [38]. Often however there are problems such as unclear directions, unavailable parking, unsuccessful delivery, or retuned

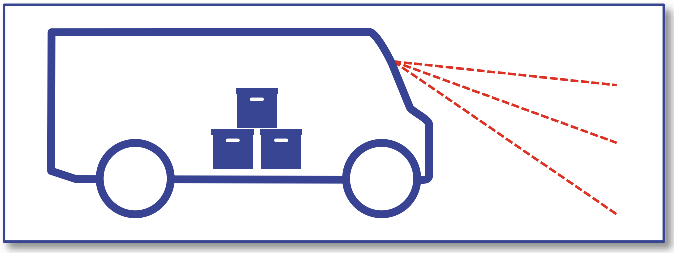


Fig. 4 Schematic depiction of an automated delivery vehicle (red lines symbolize the automation concept, such as laser beams from a LiDAR system)

shipments. The time associated with those problems increases the overall cost significantly as a human driver with a fixed salary gets less productive. Through automation however, this extra time does not matter that much, which is why automation will be very beneficial here. This concept gets even better when supplemented with those small-scale delivery robots or even drones for delivery from the vehicle to the recipient.

The necessary components to implement such automated local delivery vehicles are similar to the described shared passenger shuttles, i.e. respective sensors, processing, and infrastructure. And also very similar, those solutions can be rather early-stage and less cost effective given that those vehicles would be operated by professional entities that can check and upgrade components when necessary.

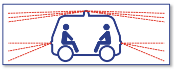
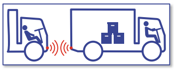
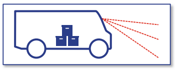
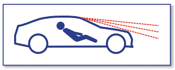
However, the operating area would probably need to be broader than for the shuttle, simply because the driving distances would be larger as otherwise shipments would need to be transferred too often between vehicles. However, those longer distances and therefore broader operating area pose higher uncertainty of the traffic and environmental setting in the service district so that the automation concept needs to meet higher performance levels than for the automated shuttle. This means that the delivery vehicles should be expected to launch after the passenger shuttle, and the middle of the next decade appears plausible for public deployment.

3 Comparison of Automated Driving Concepts

The previous parts highlighted the specific concepts that help to map out an overall deployment scenario for automated driving. While those concepts have several aspects in common, such as general sensor and processing technology, there are also important differences, which were pointed out already as they give an indication for implementation challenges and timelines. To gain an overall perspective, those aspects should be compared directly, which Table 1 summarizes.

The overview in Table 1 shows that the different concepts share largely the challenge of integration into existing traffic patters, i.e. how respective automated vehicles would negotiate situations with human driven vehicles as well as other automated ones. The solutions for this can be seen in an infrastructure, which comprises communication (vehicle-to-vehicle and vehicle-to-infrastructure), construction (dedicated areas, barriers…), and regulation (certification, general and local permits…). This infrastructure would be easier to implement and operate in a limited area, such as a specific downtown district or on a dedicated highway, than blanketing the entire nation. And also, slow speed operations help with operations because a safe state (e.g. emergency stop) can be attained immediately if needed. For those reasons, the automated shared passenger shuttle should be expected as the earliest implementation among the concepts discussed here, which is consistent with recent announcements [25–27], and the private passenger vehicle might be last to launch to public operations.

Table 1 Comparison of automation aspects for different concepts based on media research and expert interviews (L4/5 refer to SAE J3016 automation levels, + specific advantages, − specific challenges)

Concept	Specific characteristics	Steps to deployment
Shared passenger shuttles L4 	+ Finite number of routes limits unexpected situations + Pre-determined operating area allows for specific infrastructure + Slow speed reduces risk	• Implementation of special infrastructure (communication, regulation/permit…) • Further improvements of object/situation recognition
Long-haul truck platoons L4 	+ Well-defined use case makes scenarios predictable − Mixed traffic, esp. merging difficult to navigate	• Regulation to allow for special driving settings (e.g. close distance in platooning) • Infrastructure to harmonize with existing traffic patterns • Testing in real-world traffic
Local delivery vehicles L4 	+ Finite number of routes limits unexpected situations +/− Slow speed reduces risk, but difficult in mixed traffic − Drop-off from driverless vehicle at recipient still unsolved task	• Regulation, infrastructure to operate in dedicated areas • Testing in real-world traffic • Solution for automated drop-off at recipient, drones might be an option
Private passenger vehicles L5 	− Virtually infinite driving situations and operating area − Passengers expect human-like driving performance, safety/trust concerns prevail − No reliance on human supervision or fallback	• Improvement in sensor and processing technologies • Installation of roadside infrastructure (communication, construction, regulation) • Experience from earlier implementations of automation

In between the early deployments of automated shared passenger shuttles and the ultimate scenario of the automated private passenger vehicle, the launch of automated trucks is conceivable, potentially first with platooning concepts [30, 32, 33], and a bit later local delivery services. The reason why platoons might launch before local deliveries is that in platoons there is still a human in the loop, i.e. the driver of the lead vehicle, even if all following vehicles satisfy the definition of L4 automation. Local delivery vehicles however are expected to operate without any human intervention and therefore will take longer to the market, also compared to the shared passenger shuttle as the operating area of a delivery network is probably larger than the service area of a shuttle.

In this comparison it becomes clear why the L5 private passenger vehicle will probably take the longest to implementation, despite it being the most anticipated concept as pointed out at the beginning of this contribution. The reason for this lies in the virtually unlimited and therefore unknown operating domain, i.e. road, traffic, weather, etc. Therefore this uncertainty presents an infinite multitude of settings and makes the implementation most difficult and therefore probably the last to happen among the concepts discussed there. However, it also should be emphasized that all concepts build on one another and the experience that industry, regulators, and general public learn from earlier implementations prepare the path to the launch of this ultimate scenario of the L5 private passenger vehicle.

4 Hypothetical Deployment Scenario for the San Francisco Bay Area

Different deployment scenarios like the transformative (shared shuttle) and evolutionary (private vehicle) path toward automated driving were discussed in other publications already [39, 40]. And it was also already pointed out that while it seems that those two trajectories toward automated vehicles are disjoint in their timelines, they still share essential synergies regarding technical, regulatory, and societal aspects.

In order to further concretize the concepts discussed in this contribution, the following describes now in closing how an overall scenario could unfold in the San Francisco Bay Area. This region is chosen for this hypothetical scenario as there are many traffic challenges (urban sprawl, extensive industrialization, and sparsely developed public transit, all leading to traffic congestion) and also many of the automated driving players (in industry and academia) are located in that area. Taking all this and the different automation concepts together, Fig. 5 shows how the different types of automated vehicles might get deployed in this specific area. It is important to note that this is a hypothetical depiction as no one can reasonably say what is going to happen in the next 5–10 and even less 10–20 years. Therefore the following can very well be seen as some sort of a science fiction narrative. However, those scenarios should help the reader to visualize the deployment of

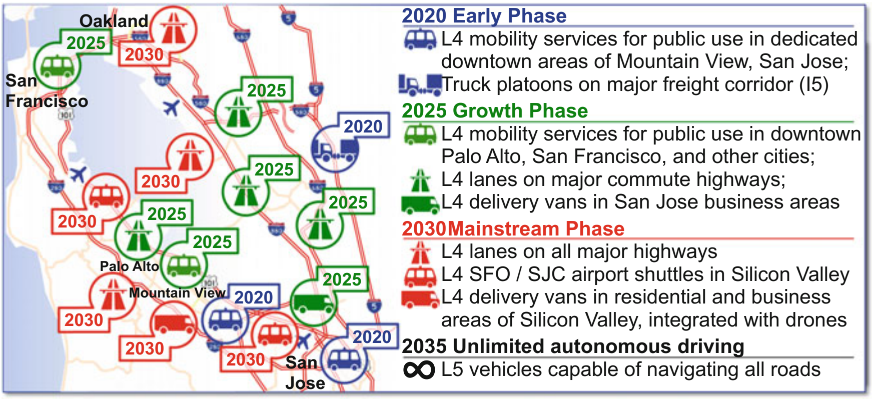


Fig. 5 Depiction of a hypothetical deployment scenario for automated driving in the San Francisco Bay Area (based on expert interviews and media research)

automated driving while keeping in mind that the narrative is based on expert interviews and extensive media research, using the theoretical assessment of the concepts per the previous parts of this contribution.

For the near future, the "Early Phase" of automated driving implementations around 2020, one can expect for the San Francisco Bay Area initial deployments of shared passenger shuttles. Those would be the services from local tech companies that are already testing respective pilot programs in Chandler (AZ) and other places [25, 26, 41, 42], which would then be brought to the home region near the companies' headquarters. There are respective announcements that make such scenarios likely [43, 44] and Mountain View, Santa Clara, and San Jose could be well situated to see the first implementations given the presence of the tech companies, a supportive regulatory environment, and the population's tech savvy. Around the same time, one might expect truck platoons on a major freight corridor like the I5, which is part of the broader San Francisco Bay area. Here again, announcements have been made, which support this scenario [45, 46].

Following this Early Phase, one can assume that a "Growth Phase" could follow around 2025, which would build upon the experience from the early deployments such as initial consumer reaction, policy revisions, and further refined on-board technology as well as roadside infrastructure. This could lead to early deployments of L4 automation on major commute highways, such as for instance I580, 680, 880 in the East Bay where telematics infrastructure like electronic toll systems (ETS) and express lanes are piloted already today [47, 48]. Evolving those telematics installations further, one can imagine L4 automation on certain lanes for especially equipped passenger vehicles and trucks. At the same time, i.e. around the middle of the 2020s, the early phase shared passenger shuttles might expand operations from initial locations to downtown San Francisco, an area that will be more difficult to navigate due to an erratic mix of pedestrians, cyclists, and any kind of motor vehicles. Such an expansion would benefit from previous experience and the deployment in a more complex setting becomes manageable. Similarly, early implementations of automated delivery vehicles might be observed in and around San Jose with the airport as a major hub for logistics companies.

In a "Mainstream Phase" around 2030 one might find L4 lanes on all major highways in the area, which would particularly benefit commuters and trucks. The latter would then add to the logistics network that provides the Bay Area with any kind of consumer and commercial goods. This is expected to improve efficiency and safety in the region of about 8 million population that is home to a vast number of businesses, the large trade port in Oakland, as well the international airports in San Francisco, San Jose, and Oakland. In addition to this, the shared passenger shuttle as well as delivery services might further expand in this phase. For instance, it becomes conceivable that respective automated shuttles transport air travelers to and from the SFO, SJC, and OAK airports. And also, the delivery services that launched earlier around the logistic hub would subsequently further expand into the metro area, enabling automated home delivery, potentially combined with drones for the drop-off at the recipient.

Finally, the L5 private passenger vehicle should not be expected before 2035, if at all, as L5 implies that the vehicle could go anywhere at any time. However, for such an unlimited operation to become possible, the situation in the rest of the nation needs to be compatible with the San Francisco Bay Area. And as such parity might take even longer than another 20 years, this scenario of unlimited L5 operation around 2035 should be seen as highly speculative. And still it could be possible as the deployment of private passenger vehicles with L5 automation would benefit from all the earlier launching automation concepts as discussed, so that this evolution will eventually reach this ultimate scenario.

5 Summary/Additional Remarks

This contribution discussed first different concepts of automated vehicles and then potential deployment scenarios specifically for the San Francisco Bay Area. The assumptions and projections are based on experts interviews conducted at the time of the Automated Vehicle Symposium 2017 and contemporary media research. The proposed overall deployment path points to automated shared shuttle services by the end of this decade, automated delivery vehicles around the middle of the 2020s, and L5 private passenger vehicles in the 2030s. Across those phases, different concepts in truck automation are expected, first with platoons and later single vehicle automation.

It is a crucial aspect of this contribution that those projections were developed specifically for the San Francisco Bay Area as there are unique characteristics in terms of technology presence, traffic challenges, as well as economic and political interests. Other regions have different characteristics and respective scenarios vary in their timelines and automation concepts. Thereby it is also important to note that this contribution does not provide exact dates for the deployment of specific automation concepts but rather proposes phases when respective implementations can be expected.

Therefore it can be maintained that those scenarios are hypothetical if not speculative as no one can safely say what the situation in technology, regulation, and society will be like in 5, 10, 20 years from now. However, this contribution took expert opinions and media coverage in the vehicle automation field to come up with a comprehensive perspective. Further work is encouraged to increase accuracy as well as detail regarding those scenarios. They will certainly change as time progresses. In that sense, this contribution closes with a quote that fits well:

> We always overestimate the change that will occur in the next two years and underestimate the change that will occur in the next 10. Don’t let yourself be lulled into inaction. Bill Gates, [49]

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Shared Automated Vehicle (SAV) Pilots and Automated Vehicle Policy in the U.S.: Current and Future Developments

Adam Stocker and Susan Shaheen

Abstract Many automated vehicle (AV) developers and technology companies are fast pursuing the public deployment of these vehicles as part of a shared fleet. To the best of our knowledge, this chapter is the first comprehensive compilation of 17 active shared automated vehicle (SAV) pilot projects in the U.S., as of February 2018. This chapter also reviews AV regulatory efforts at the federal, state, and local levels. By tracking trends and classifying the differences between SAV pilots, we foster a better understanding of how this technology might roll out in the coming decades. While 30 states have enacted legislation or executive orders related to AVs, only two states' regulations contain provisions related to SAVs. Although future impacts of SAVs are still uncertain, this chapter begins the dialogue around the need for proactive SAV legislation to help guide beneficial societal outcomes of these emerging services.

Keywords Shared automated vehicles · Automated vehicles · Shared mobility
Automated vehicle policy · Automated vehicle pilots

1 Introduction

Automated vehicles (AVs) are vehicles that move passengers or freight with some level of automation that assists or replaces human control. AVs are being developed by over 40 companies around the world, including most major automakers and many large technology companies [1]. Between August 2014 and June 2017, there were more than 160 AV-related investments, partnerships, and acquisitions, totaling approximately $80 billion dollars [2]. With the ongoing growth of shared mobility

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services (carsharing, ridesourcing/transportation network companies (TNCs), ridesharing, bikesharing, and microtransit), many companies are interested in deploying shared AV fleets. Shared automated vehicles (SAVs) are AVs that are shared among multiple users and can be summoned on-demand similar to ridesourcing or can operate a fixed-route service like a bus. For the purposes of this research effort, we consider SAV services to be those that operate or intend to operate as a shared vehicle fleet that serves passengers in one or more travel use cases.

The Society of Automotive Engineers (SAE) have 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 [3]. The majority of SAV 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. Almost all SAV pilots are aiming for Level 4 automation because the viability of future SAV business models depends on the absence of human monitors inside the vehicles. For this reason, the ODD is arguably more important than the level of automation, when discussing differences between SAV pilots. The ODD describes the specific conditions under which a given automated feature is intended to function. The ODD is the definition of where (roadway types and speed limits) and when (during what weather conditions, time of day, etc.) an AV is designed to operate [3]. SAVs differ in their scope of operations depending on the ODD, which we explore further in this chapter.

We are at the beginning stages of active SAV pilots in the U.S. and around the world. At present, all SAV pilots mentioned in this chapter have a safety engineer inside the vehicle at all times who can intervene and take control of the AV, if necessary. We are also at the early stages of AV and SAV regulations at the U.S. federal, state, and local levels of governance. While 29 U.S. states and the District of Columbia (DC) have passed legislation or issued executive orders related to AVs, there are no AV-specific laws enacted at the federal level, at present. In addition, legislation in only two states contains measures related to SAVs at this time. This chapter focuses on SAV pilots and legislation in the U.S., but please note that there are many developments around the world. The range of challenges and opportunities of SAVs are yet to be fully understood and are difficult to predict. However, the potentially lower cost per-mile of future SAV services could increase travel demand, possibly leading to a number of negative societal effects like increased vehicle miles traveled (VMT), emissions, and urban sprawl. Future SAV policy will be critical to help mitigate the potential negative impacts of these services and encourage higher-occupancy travel. This chapter serves as a compilation of SAV developments in the U.S. and uncovers trends among SAV pilots and legislation thus far. Understanding how SAVs are developing and might develop in the near future is critical when exploring possible policy actions regarding this emerging form of mobility.

2 Shared Automated Vehicle (SAV) Pilots

There have been a number of SAV developments in the U.S. over the past few years, and the pace at which pilot projects are launching appears to be speeding up. In this section, we track and map all of the continuously operating SAV pilots in the U.S. and classify whether the program is:

(1) Serving passengers or testing only,
(2) Operating on public or private roads, and
(3) Using a low-speed shuttle or a conventional vehicle.

We chose to classify SAV pilots across these three dimensions because they gauge how close each particular pilot may be to deploying and help to clarify the ODD and use case that the program is targeting. The private or public road distinction is important for regulation considerations. In almost all cases, AVs on private roads do not need to follow state regulations. Of course, these classifications could change over time as services move from testing to the deployment phase or begin to travel on additional roadways. These classifications represent the state of the SAV pilots, to the best of our knowledge, as of February 2018. Please note that we only include continuous and current SAV pilots and do not include temporary demonstrations or pilots that have ceased operations. At present, all of these SAV pilots have one or more backup safety engineers inside the vehicle, who are ready to take over in case there is a problem with the automated driving system. In addition, all of the AVs listed are Level 4 automation, unless otherwise specified. Figure 1 maps all active SAV pilot programs in the U.S.

There are 17 active SAV pilots across eight states around the U.S., eight of which are serving passengers and nine of which are in a testing only phase. The

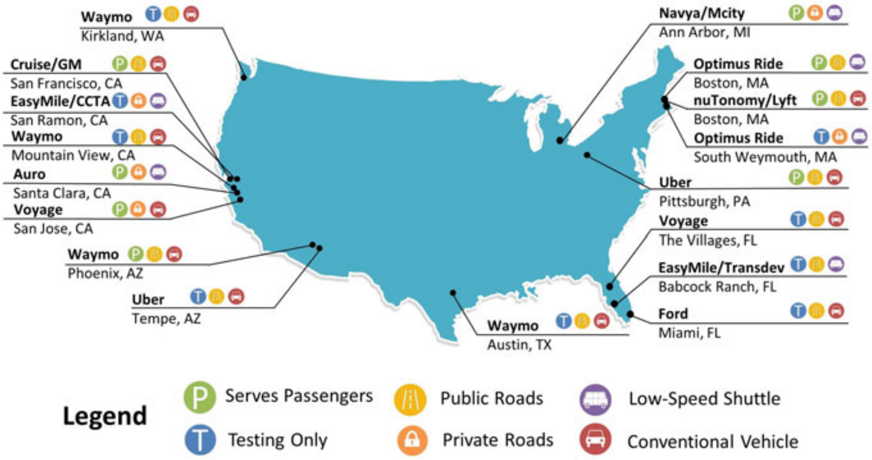


Fig. 1 Active SAV pilots in the U.S., as of February 2018

majority of SAV pilots operate on at least some public roadways, though five pilots only operate on private roads, at present. A mix of vehicle types are used in SAV pilots, although larger players tend to prefer conventional vehicles (11 pilots in total). Smaller, more specialized companies often use low-speed shuttles (six pilots in total). Across the active U.S. SAV pilots, two distinct pilot types emerge, largely depending on the ODD. The following discussion focuses on SAV pilots operating on: (1) private roads and in planned communities and (2) public roads and city streets. We describe in further detail only those pilots serving passengers.

2.1 Private Roads and Planned Communities

SAV pilots on private roads and in planned communities operate in low-speed, controlled environments, and sometimes use specialized shuttles designed to travel under 30 miles per h. These pilots often focus on serving specific locations or passenger markets, such as: office parks, housing developments, retirement communities, and universities. SAV pilots in testing phase that also fall under this category include: (1) EasyMile/CCTA at Bishop Ranch; (2) Optimus Ride in South Weymouth; (3) Voyage at The Villages, Florida; and (4) Easymile/Transdev at Babcock Ranch. The SAV pilots serving passengers in this category are described in Table 1.

2.2 Public Roads and City Streets

The other group of SAV pilots operate on city or suburban streets, and most use conventional vehicles equipped with AV technology to navigate their surroundings, often in mixed traffic. SAV pilots still in the testing phase that fall into this category include: (1) Waymo in Mountain View, California, Austin, Texas, and Kirkland, Washington, (2) Uber in Tempe, Arizona, and (3) Ford in Miami, Florida. All SAV pilots listed use pre-selected passengers and are not open to all members of the public. The current SAV pilots in this category are described in Table 2.

2.3 Planned SAV Developments

Many major automotive and technology companies have announced plans to increase their AV fleet size and further develop and launch SAV services in the coming years. In January 2018, Waymo announced plans to add thousands more automated Chrysler Pacifica Minivans to its existing fleet [4]. Similarly, Uber reportedly agreed to buy 24,000 automated XC90s from Volvo to be delivered from 2019 to 2021 [5]. In late-2017, GM announced plans to deploy fleets of SAVs in

Table 1 Private road and planned community SAV pilots serving passengers

Operator(s)	Location	Description
Auro Robotics	Santa Clara University, CA	Auro Robotics operates their low-speed AVs at Santa Clara University in California. The vehicle is a retrofitted Polaris GEM electric four-seater golf cart. It operates a fixed route service on campus for eight hours most days and three hours on sundays. The pilot became fully operational on November 14, 2016, and an Auro field engineer rides along in the driver's seat to take control, if needed. In October 2017, the mobility platform company Ridecell acquired Auro with hopes to offer a pre-packaged solution for SAV services, focusing on low-speed vehicles deployed on private property [31]
Navya/Mcity	University of Michigan, Ann Arbor, MI	The Navya ARMA is an electric low-speed automated shuttle that can transport up to 15 passengers. The vehicle began testing at Mcity, the University of Michigan's 32-acre test facility for AVs in December 2016. In Fall 2017, two of the AVs began shuttling students, faculty, and staff on a two-mile route between the engineering campus and the university's North Campus Research Complex. The SAV service is operated by Mcity [32]
Voyage	The Villages, San Jose, CA	The Villages is a 4000-resident gated retirement community in San Jose, California, containing about 15 miles of private roadways. Since October 2017, Voyage, a Udacity spin-off, has operated three of its Ford Fusion AVs as an on-demand SAV service for residents inside the community [33]. Please note this is different from Voyage's testing efforts at The Villages in Florida

large cities by 2019, and in January 2018, GM unveiled an AV design without a brake pedal or a steering wheel that it hopes to test in 2019 [6]. In addition to the larger players, smaller companies have ambitious plans as well. Navya unveiled its electric Autonom Cab designed specifically for SAV passenger services, with capacity for six passengers and center-facing interior benches [7]. In addition to its current developments, EasyMile and the San Francisco County Transportation Authority are planning a pilot to serve passengers for first- and last-mile trips to public transit on Treasure Island, California by 2020 [8]. These are just a few examples of planned SAV developments, although there exist many more announcements and partnerships with the aim of developing AV technology and SAV services.

Table 2 Public road and city street SAV pilots serving passengers

Operator(s)	Location	Description
Uber	Pittsburgh, PA	In September 2016, Uber began a SAV pilot in Pittsburgh, Pennsylvania using automated Ford Fusions. The pilot was the first SAV service in the U.S. to pick up passengers. The pilot is open to frequent uberX customers who can request a vehicle through the Uber app. At the start of 2017, the company fully transitioned its Pittsburgh fleet to Volvo XC90 SUVs equipped with AV technology. The AVs contain a backup driver plus a technician in the front passenger seat. Uber plans to incrementally remove technicians in 2018 [34]
Cruise/GM	San Francisco, CA	In February 2017, GM's Cruise began testing its automated Chevrolet Bolt EVs on roads in San Francisco, California, allowing select employees to commute to work using the vehicles. In August 2017, Cruise expanded the pilot, allowing additional employees to participate and request more than just work trips via an app called Cruise Anywhere [35]. The AVs contain test drivers in the passenger seat, as required by the California DMV. As of November 2017, GM had about 180 automated Chevrolet Bolt EVs in their fleet, some of which are being tested in Arizona and Michigan [36]
Waymo	Phoenix area, AZ	Alphabet's Waymo launched its Early Rider program in April 2017, inviting select residents of parts of the Phoenix metropolitan area to request rides in their automated Chrysler Pacifica Minivans. The AVs initially contained Waymo test engineers in the driver's seat, but they have since moved to the back seat in November 2017, meaning the AVs operate without a human directly behind the wheel [37]. Waymo received a TNC permit in Arizona in January 2018, and the company plans to launch a commercial SAV service to members of the public in the Phoenix area in 2018 [9]
NuTonomy/ Lyft	Boston Seaport, MA	NuTonomy has tested its automated Renault Zoe EVs in the Seaport and Fort Point areas of Boston since April 2017. In June 2017, Lyft and NuTonomy formed a partnership, and in December 2017, they launched a SAV pilot that will allow select Lyft riders in the Seaport area to be matched with a NuTonomy AV through the Lyft app [38]. NuTonomy has passed multiple phases of AV testing, as required by a city-level mayor's executive order [39]
Optimus Ride	Boston Seaport, MA	Optimus Ride has tested its low-speed electric AVs on streets in the Raymond Flynn Marine Park area since June 2017. In January 2018, the company was approved by city officials to carry passengers in its AVs within the Marine Park area [40]. The company is testing first- and last-mile service routes on public roads and is offering rides to employees of businesses in the area. Optimus Ride is at an earlier stage of testing with the city than is NuTonomy (who is also testing in the Seaport area); thus, their operations are restricted to the Marine Park area [39]

2.4 Key Trends Discussion

Not surprisingly, we are beginning to see some trends emerge in the U.S. SAV developments. First, no company has a commercial SAV service that is providing rides to the general public. The pilots that are serving passengers do not offer their services to the public. Instead, they only transport select passengers or members of a closed group like a university, workplace, or retirement community. Waymo is likely the closest to making their Phoenix-area SAV pilot into a commercial service and has plans for public deployment in [9]. SAV pilots in the U.S. are largely taking place on the coasts, often in states with warm weather year round, like California, Arizona, and Florida. Some of the trends in location are partially due to favorable regulatory environments in certain states; we discuss this in the next section. In the next few years, more AV pilots will likely emerge that test vehicles in more demanding weather conditions. Some companies have already started testing in snowy areas to assess how their vehicles perform there. Waymo began testing its AVs in Winter 2017 in Detroit [10], and EasyMile began a temporary winter pilot with its EZ10s in Minnesota in late-2017 [11].

In addition, all of the pilots have started very recently. Other than Waymo's AV fleet testing efforts that first began in 2012 as the Google Self-Driving Car Project, almost all of the SAV pilots began in the last 18 months. About half started within the last six months. A number of SAV passenger pilots in major U.S. cities launched during late-2016 and early-2017 (Uber in Pittsburgh, Cruise/GM in San Francisco, Waymo in Phoenix, and NuTonomy/Lyft in Boston), and these programs are making incremental improvements to their technology and preparing for public deployment. A number of the private road and planned community SAV pilots launched even more recently (i.e., within the last six months). SAV services that target low-speed and controlled environments are launching in new locations at a fast pace, and many are beginning to serve passengers. Given these developments, we will most likely see more SAV pilots emerge in 2018 and in the near-term future. In the longer term (ten to twenty years), city-level SAV programs will likely gain a much larger market share of U.S. passenger-miles than their low-speed counterparts. As shown in this analysis, large automakers and technology companies are at the beginning stages of developing SAVs for the city- or regional-level transportation market. This will likely become more competitive in the coming years and decades. On the other hand, smaller players will continue to target more niche markets and use cases, which allows for faster SAV deployment due to specially designed vehicles that do not need to function across a wide range of environments.

Despite these advancements, it is still unclear how long it will take until test engineers can be removed from SAVs. At present, all SAV developments in the U.S. have a test engineer on board. Waymo's decision to have their test engineers ride in the back seat in its Phoenix-area program is the most significant SAV development thus far toward removing the need for physical staff presence in a SAV. However, it is not clear at this time when companies will begin removing test staff from their vehicles and there is no common framework for what factors determine when they could safely be removed. Some of the low-speed SAV pilots could likely be the first in the U.S. to remove the test engineer from the vehicle, since their operating environments are often safer than those in which an AV is operating in mixed and possibly high-speed traffic. For example, the EasyMile/Transdev pilot in Babcock Ranch plans to remove the test engineer once enough testing has taken place. They will have an emergency button in the vehicle that would contact a remote safety operator [12]. Many companies testing AVs are developing remote operations capabilities, where a human operator in a control center can take over and safely maneuver or stop an AV in case of malfunctions or emergencies. Regulation will play a key role in defining many factors around AV safety, operations, and design requirements. We explore AV policy at the federal, state, and local levels in the U.S. in the following section.

3 U.S. Automated Vehicle (AV) Policy Overview

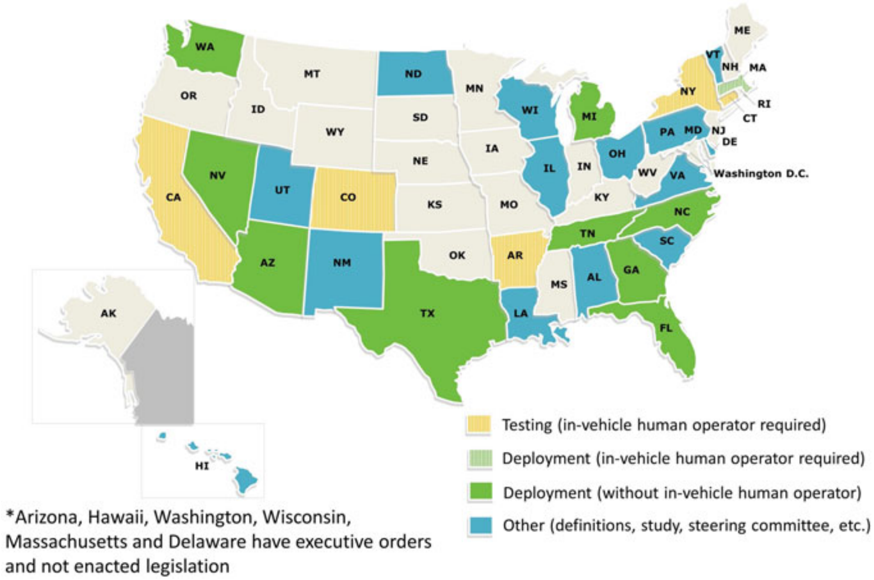
While there are very few SAV-specific policies or regulations, at present, there are a number of states with AV legislation or executive orders, along with federal and local level activity. To date, most AV legislation relates to road safety, liability and insurance, vehicle design requirements, and operational area. In this section, we discuss AV legislation and regulatory roles in the U.S. across: (1) federal, (2) state, and (3) local levels of governance.

3.1 Federal AV Policy

While there are no federal AV laws enacted at present, there has been activity in the last few years toward creating a framework and legislation around AVs. In September 2016, the National Highway Traffic Safety Administration (NHTSA), under the Obama administration, released their Federal Automated Vehicles Policy document that is intended to establish a 15-point framework for AV regulation in the U.S. This document was not intended as a concrete rulemaking but rather to provide recommendations on safety, data sharing, privacy, cybersecurity, and ethical considerations, among others [3]. NHTSA released a second iteration of the document titled Automated Driving Systems 2.0 (ADS 2.0) in September 2017, under the Trump administration. This iteration shortened the guidance and decreased the safety self-assessment from 15 to 12 areas. The document clarifies that entities do not need to wait for Federal approval to test or deploy their AVs. Similar to the first iteration, the guidelines remain voluntary [13]. A week prior to the release of ADS 2.0, the U.S. House passed the SELF DRIVE Act, a bill that aims to establish a federal framework for AV regulation. It proposes a dramatic increase in the number of exemptions from existing federal motor vehicle safety standards (FMVSS). A similar bill titled the AV START Act passed a Senate committee in October 2017, but it remains stalled in the Senate due to safety concerns, at present [14]. The bill would allow exemptions for up to 15,000 AVs per company in the first year, 40,000 by the second year of the law, and 80,000 per year thereafter. If passed in its current form, state legislation would be broadly preempted in the areas of: system safety, data recording, cybersecurity, human-machine interface, crashworthiness, capabilities of AVs or systems, post-crash behavior, vehicle programming to meet existing traffic laws, and automation function. The proposed bill also excludes large commercial vehicles. However, it must be approved by the Senate and merged with the House AV bill before becoming law [15]. While there are no enacted laws at the federal level, there are many that have been passed at the state level, which we discuss below.

3.2 *State AV Policy*

To date, 23 states and DC have enacted or adopted legislation, and Governors in six states have issued executive orders related to AVs [16]. These laws typically regulate liability and insurance, licensing, registration, traffic rules, and infrastructure. A small number of state laws contain aspects that relate to SAVs, which we discuss in this section. Figure 2 compares the differences in AV state regulations on testing and deployment and whether there is a requirement for a human backup driver to be



*Arizona, Hawaii, Washington, Wisconsin, Massachusetts and Delaware have executive orders and not enacted legislation

Fig. 2 Map of state AV legislation and executive orders physically present inside the vehicle. This tracking methodology serves as a barometer for how close each state is to legally allowing commercial SAV services on public roadways. In Fig. 2, testing denotes the allowance of AVs on public roadways and deployment refers to the authorization of passengers who are not necessarily registered AV test drivers. Note that some states use the terminology "operation" to refer to stages beyond the testing phase, which we designate as deployment in Fig. 2.

As of February 2018, 29 states and DC have passed legislation or issued an executive order related to AVs. Fifteen states and DC have passed legislation or issued an executive order that allows for either AV testing or deployment on public roads. The other 14 states have enacted legislation or an executive order that does not relate to AV testing or deployment but to other AV-related measures such as requiring studies or forming steering committees. Five states have approved AV testing only (with an in-vehicle human operator), Massachusetts and DC allow deployment with passengers (with an in-vehicle human operator), and nine states permit full deployment without an operator required inside the vehicle. We classify state AV laws in this manner because SAV deployment without an in-vehicle human operator will be essential for the scaling and financial feasibility of commercial SAV services. So far, Florida, Arizona, Washington, Nevada, Texas, Georgia, Tennessee, North Carolina, and Michigan are the nine states that allow for AV deployment without an in-vehicle human monitor. While states might have favorable AV laws, this does not mean companies will choose to test or deploy there. For example, out of the 11 states that allow for SAV deployment, only four (Florida, Washington, Texas, and Massachusetts) have active SAV pilots in their states. The number of states allowing AV deployment will likely increase in the coming years, and many states are working on deployment regulations. As mentioned previously, only a few states include provisions in their AV legislation that specifically relate to SAVs. Michigan's Senate Bills 995 and 996, passed in late-2016, initially required that "on-demand automated motor vehicle networks" be controlled by the vehicle manufacturer. However, revised bill language clarifies that a manufacturer need to only supply the vehicles used in a SAV network [17]. Assembly Bill 1444 in California authorizes the Livermore Amador Valley Transit Authority to conduct a SAV demonstration project without a driver, steering wheel, or brake pedal, but the bill only lasts for a six-month demonstration period [16]. Some state bills are beginning to address the taxation of AV and SAV operations. Both Nevada and Tennessee have enacted taxation legislation related to SAVs at this time, as outlined in Table 3.

Massachusetts has proposed a similar law that would levy a 2.5 cent-per-mile tax on AVs [18]. However, no SAV-specific taxes have been applied in practice, since neither of these two states has any active SAV pilot. While around half of the U.S. states have passed laws or issued executive orders regarding AVs, there are much fewer that have developed laws related to the management and operations of SAV fleets. Many more states will likely consider SAV-specific legislation as pilots expand to serve public passengers.

Table 3 State AV taxation legislation

State/Bill	Tax	Description
Nevada (Assembly Bill 69)	3% of total SAV fare	The most comprehensive enacted legislation related to SAVs at this time, AB 69 contains a number of provisions around what it calls "autonomous vehicle network companies." The bill authorizes an excise tax on SAV services at 3% of the total fare charged for each ride. It also contains specific provisions to ensure this tax does not apply to those carpooling with AVs, and it accounts for wheelchair accessibility of SAV services [41]
Tennessee (Senate Bill 1561)	1 cent-per-mile (passenger AVs) 2.6 cent-per-mile (AV trucks)	SB 1561 imposes a one cent-per-mile tax on AV passenger vehicles and a 2.6 cent-per-mile tax on AV trucks with more than two axles [18, 42]. The state plans to divide the revenue from the tax between the state general fund, state highway fund, counties, and localities according to a statutory formula [43]

3.3 *Local AV Policy: Case Study of the City of Boston*

In the U.S., there has been less local AV policy activity in contrast to the states. As more AVs operate on public roadways, local AV policy will likely regulate areas of AV and SAV operations, rights-of-way access, and local taxation. There have been a number of local laws across the nation, which allow for short-term AV demonstrations, but fewer allow for sustained AV operations [19]. One of the most comprehensive local AV policy programs is overseen by the City of Boston. Boston mayor Martin Walsh signed an executive order in October 2016 that established a multi-phase AV testing program in the city. Boston requires operators to complete a memorandum of understanding with appropriate parties and submit an application with the Massachusetts Department of Transportation before operating. The city regulates the time, place, and manner of testing and is initially restricting testing to a 1000-acre area of the South Boston Waterfront. The city also requires quarterly data reports of the two companies that are currently testing in Boston (nuTonomy and Optimus Ride). These reports include metrics like: number of passenger trips, passenger home zip codes, trip origin and destination, and qualitative user feedback [20, 21]. Other efforts at the local level include the formation of working groups, statements of principles, and the creation of roadmaps [22]. Although there are not many local AV regulations at present, these laws will likely be very important in mitigating the negative impacts of SAV operations by crafting rules that address traffic congestion, urban sprawl, and equity in each city or region.

3.4 Upcoming AV Policy Developments

Many more policy developments in the AV and SAV space are expected over the next few years and decades. In addition to the Senate's AV bill, NHTSA is preparing version 3.0 of its AV policy document and plans to include others beyond NHTSA, which will take part in overseeing the implementation of AV technologies. These regulatory bodies include the: Federal Motor Carrier Safety Administration (FMCSA), Federal Transit Administration (FTA), and Federal Highway Administration (FHWA) [23]. Although many states are hoping to pass new or additional AV regulations, the proposed California AV deployment regulations will arguably be one of the most important state legislations to come out in 2018 due to the number of companies located and testing in California. The regulations, which were recently approved by the Office of Administrative Law, are expected to take effect in April 2018 and will allow AVs without steering wheels, brake pedals, and in-vehicle human operators on public roads in the state [24].

3.5 Key Trends Discussion

At present, most policy activity around AVs is happening at the state level, with 29 states and DC passing legislation regarding public safety, legal frameworks, and requirements for insurance and liability. Key trends at the state level include:

- Nevada was the first state to pass legislation and authorize the operation of AVs in 2011,
- By 2013, three more states (California, Florida, and Michigan) and Washington DC passed bills defining various aspects of AV operations and allowed for testing on public roads,
- Florida was the first state to allow anyone with a driver's license to operate an AV on state roads. Florida was also the first state to allow the operation of AVs without a human present in the vehicle (i.e., House Bill 7027 in April 2016) [25],
- Now, nine states allow AVs without a physical operator on public roads, and more states are likely to move in this direction.

Although uncommon, more states may begin to enact per-mile or per-ride charges on SAV services, similar to Tennessee and Nevada. From 2015 through 2017, 16 states across the nation have passed an increase in their state gas taxes [26], signaling that some legislators are willing to explore creative ways to raise infrastructure funding in the absence of a federal gas tax increase. This stance may foster interest in taxing AVs, and in the coming years may see more states enact taxation mechanisms for this emerging vehicle technology. In addition, more local and regional laws will step in as an increasing number of SAV pilots are deployed. The unique urban forms of different cities will likely require cities and regional planning organizations to develop more precise guidance for testing and deployment of SAV services. SAV services will likely require close coordination with local transportation authorities, as is the case in the two SAV pilots in Boston. Federal legislation will likely impact the authority of states and localities, as suggested by the current Senate AV START bill that would preempt states from setting their own laws around AV design and safety functions. This could cause challenges, if some states do not agree with direction of the federal regulations.

4 Potential SAV Impacts and Future Policy Developments

Impacts of AVs and SAV services on travel behavior, the urban form, and the environment are unclear. Some studies predict that roadway capacity could be increased due to more efficient operations and right-sizing of AVs, while other studies predict increased vehicle miles traveled (VMT) as a result of cheaper and more convenient AV and SAV travel options [27]. The range of predicted impacts often depends on market penetration assumptions of SAVs compared to privately owned AVs. A study of predicted AV energy impacts by Ross and Guhathakurta [28] compiled findings across multiple leading studies and noted that most authors found that full automation is likely to result in more energy consumption because it will allow vehicles to travel faster, which could induce travel demand and spark new user groups. However, dynamic pooling with SAVs may be able to reduce energy consumption depending on the proportion of trips that are shared among riders. The studies analyzed by Ross and Guhathakurta [28] find that under these scenarios, total energy consumption may be reduced by more than half compared to the present day even though more VMT may be generated due to assumptions about vehicle fleet electrification.

Although the impacts of AVs and SAVs remain uncertain, multiple studies predict that emissions would be lower under a SAV scenario (especially with dynamic pooling) than a personally owned AV scenario. Future policy development in this area should take these findings into account and try to encourage not only SAVs (over private AVs) but the pooling of multiple passengers per trip (over single-occupant vehicles). Policies that more adequately charge road users for their externalities, including usage-based pricing and pooling incentives, could encourage more sustainable AV and SAV outcomes. Some of these policies are already being piloted and developed today with non-AVs.

Road usage charging (RUC) is the concept of pricing transportation infrastructure to collect funds or to achieve a desired outcome. There are different approaches to RUC, some of which have been adopted in parts of Europe and Asia. These approaches include: VMT pricing, cordon pricing, express lanes, and other methods [29]. Road pricing is gaining in popularity in the U.S., although most efforts thus far have been pilot programs at the state level. For AVs and SAVs, RUC will be an important component in mitigating some of the potential negative externalities on congestion, the environment, and equity. If AVs and SAVs are appropriately priced based on their usage, higher-occupancy forms of transportation may become more attractive and gain higher ridership than would be the case absent of any road pricing regulations. Shared-ride services, any transportation mode that allows riders to share a ride to a common destination, may become more popular as well. Examples of shared-ride services that exist today include: public transportation, ridesharing (carpooling and vanpooling), pooling (e.g., Lyft Line and UberPOOL), taxisplitting, and microtransit [30]. High-occupancy vehicle (HOV) lanes are a common example of public rights-of-way policies that aims to encourage the use of shared rides, although more specific policies may be developed for AV and SAV services.

For SAVs, while incentives for shared rides could help mitigate some negative externalities, these incentives alone will not be enough. A combination of pooling incentives with various forms of RUC and access to rights-of-way policies, tailored to city and regional travel patterns, will be necessary to curb the potential negative impacts of AVs and SAVs (e.g., equity, congestion, public transit displacement, etc.). While RUC and other forms of pricing and pooling incentives are not new, the amount of data generated by SAVs will make it easier to track and charge travel with measurable metrics like time of day, VMT/GHGs, location, vehicle type, and occupancy [29]. In addition, if SAV services become widespread, it could become easier to impose usage-based taxes on a few centralized entities than it is today on millions of individual road users. While we are at the early stages of AV pricing and only a couple of states in the U.S. have enacted basic usage-based taxes on SAV services, this topic will likely have a large impact on AVs and SAV impacts on the environment, traffic congestion, public transit, and equity in the coming decades.

5 Conclusion

While it is still early in SAV development, pilot projects are expanding rapidly, with 17 active SAV pilots in the U.S., as of February 2018. Most of the pilots began in the last 18 months and about half launched during the past six months. There are 29 states and DC with legislation or executive orders related to AVs. However, enacted legislation in only two states contains tax provisions related to SAV fleets. In addition, not many local government entities have developed SAV regulations. Given that most SAV pilots are small scale and do not involve public passengers at this time, the lack of SAV regulation has not arisen as a major concern. However, SAV policy may become a more pressing priority as AV technology improves and companies increasingly deploy public services. Policymakers must therefore be proactive in developing appropriate rules around AVs and SAV services. Once deployed and SAV service models become more commonplace, it will be hard to enact pricing regulations after the fact. Therefore, policy action is needed to mitigate the potential negative externalities of AVs and SAVs. Collaboration between public and private sector players will be important in encouraging the safe, sustainable, and equitable deployment of SAVs.

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Deployment of Automated Trucking: Challenges and Opportunities

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Abstract Based on the outcomes from the automated trucking breakout session at the 2017 Automated Vehicles Symposium, this Chapter reviews the current state-of-the-art of automated trucking applications and discusses key factors expected to influence their deployment. It is suggested that a key challenge for the deployment of automation in the trucking domain is that the business models are typically linked to specific and strongly heterogeneous transport operations, each of which associated with a specific set of deployment factors. To handle this complexity, strategic partnerships are expected to be formed between stakeholders, where business models and other deployment factors can be addressed jointly, and in a step-wise fashion, for specific automated trucking operations.

Keywords Trucking · Automation · State-of-the-art · Deployment
Platooning · Highway automation · Business models · Safety assurance regulation
Public acceptance and trust · Automation impacts on labor

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1 Introduction

The automation of on-road trucking operations is a currently hot topic. Whereas automated trucking is already a reality in off-road application domains such as mining, commercially available on-road automation applications for trucks are still largely limited to lower-level automation functions such as adaptive cruise control (ACC). However, automated driving technologies are developing at a rapid pace and a range of more advanced automated trucking applications have recently been developed and demonstrated on public roads including platooning, exit-to-exit highway automation, traffic jam assist, automated trailer backing and parcel delivery automation. The potential safety improvements, emission reductions and cost savings associated with these applications have created a strong interest from key stakeholders including the trucking industry and their shipping clients, traditional truck manufacturers, new tech companies supported by venture capital, as well as federal and state-level transportation authorities. While technological challenges certainly remain for the higher levels of automation, many of the key hurdles for large-scale deployment of automated trucks with lower levels of automation on public roads are related to non-technical issues such as business models, organizational implementation issues, regulation and attitudes among the general public towards automated trucks.

The general objective of this Chapter is to review the current state of the art in automated trucking technologies and discuss some of the key current deployment challenges and opportunities. The focus is mainly on truck platooning and exit-to-exit highway automation although other types of automated trucking applications are briefly addressed as well. In addition, some lessons learned from the successful deployment of automated trucking in the mining domain are reviewed.

The Chapter is based on the outcomes of the automated trucking breakout session at the Automated Vehicles Symposium, co-sponsored by the National Academies Transportation Research Board (TRB) and the Association of Unmanned Vehicle Systems International (AUVSI), held in San Francisco, July 11–13, 2017 (AVS17). The breakout session included a set of presentations

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providing an overview of the current state-of-the-art of automated trucks and identifying key deployment issues. Two panels with key stakeholders were focused on platooning and highway automation applications respectively, while two deep dive sessions offered the opportunity for more detailed discussion (see the Acknowledgements section below for a full list of contributors to the session). PowerPoint files of most of the presentations are available on the AVS website at http://www.automatedvehiclessymposium.org.

The present Chapter, like the breakout session, focuses mainly on the situation in the US and it should be kept in mind that the deployment of trucking automation technologies may be subject to quite different constraints in other regions such as Europe, China and Japan.

2 Current State-of-the-Art in Automated Trucking

As mentioned above, there is a range of automated trucking technologies and applications. Here we will mainly focus on the two types of applications that have been considered for near-term deployment on public roads: platooning and exit-to-exit highway automation. In addition, we briefly address existing automated trucking applications in off-road domains such as mine hauling, trailer switching, drayage and manufacturing/distribution in dispersed local sites.

2.1 Truck Platooning

Truck platooning refers to two or more trucks driving under coordinated automatic longitudinal control at relatively short following distances. Truck platooning is attractive for several reasons, including energy savings from aerodynamic drafting, more stable vehicle following dynamics, reduced traffic flow disturbances (which has additional savings in energy and emissions) as well as potential safety improvements.

Truck platooning builds on Cooperative ACC (CACC) technologies, which have also been explored for passenger cars. CACC uses vehicle-to-vehicle (V2V) communication/coordination to enable constant time-gap following and ad hoc joining and leaving the platoon. Truck platooning may extend the CACC concept by adding coordination/supervision by the lead truck, a constant clearance distance gap and typically shorter following distances than for CACC. It should be stressed that platooning is not a recent invention but the result of incremental research and development going back at least to the CHAFFEUR EU-funded project [1, 2] in the late 1990s and early 2000s. Recent major initiatives include the FHWA-sponsored Exploratory Advanced Research Program (EARP) projects performed by California PATH [3–6] and Auburn University [7, 8] and the European Truck Platooning Challenge [9].

Platooning functions may be roughly characterized based on the Levels of Automation defined in the Society of Automotive Engineers (SAE) J3016 standard [10]. Level 1 platooning here refers to systems that only automate longitudinal vehicle control (i.e., automatically maintains a constant time gap or clearance distance in the presence of a lead vehicle) while the driver remains in control over lateral control (i.e., steering). There are several recent or ongoing research and development projects on Level 1 platooning such as the UC-Berkeley/California PATH and Auburn University EARP projects mentioned above [3–8]. The startup Peloton Technology, which launched in 2013, participated in a USDOT-sponsored platooning study with Auburn University and have announced plans to deliver commercial systems to customers in 2018. Several truck manufacturers have also announced that they are nearing market introduction of platooning applications in North America although it is not always clear if these will be labelled as SAE Level 1 or 2. Internationally, important platooning field tests are underway or getting started in Australia, Germany, Japan, Netherlands, Singapore, Sweden, and the U.K.

Level 2 platooning adds automatic steering control. Research indicates that this is necessary to enable shorter longitudinal gaps due to visibility limitations for the following driver at shorter distances which makes manual steering difficult [7]. Multiple research projects have tested and demonstrated Level 2 platooning, from CHAUFFEUR [1, 2] to Konvoi [11], SARTRE [12] and Energy ITS [13]. The Texas Transportation Institute is currently working to trial Level 2 platooning in Texas. Several truck manufacturers and tech companies are currently conducting research and development, including public road testing, on Level 2 platooning.

In Level 3 platooning, the driver can divert attention temporarily to other tasks, but is expected to remain available to intervene when needed. Level 4 platooning additionally assumes an ability to ensure achieving a minimal risk condition under any fault condition without any human intervention (while operating within its specified Operational Design Domain, ODD). Level 3–4 platoon followers may also be coupled behind a leader driven at a lower automation level. Operating Level 3–4 platoons places high demands on safety assurance, and many practitioners believe that the current state of the art is currently insufficient to support this level of automation for mixed traffic and highway-speed operations. Thus, in the near term, L3–4 platoons may be limited to enclosed sites such as ports or segregated truck-only lanes to simplify the ODD. However, in Singapore there are plans to implement L4 platooning on public roads [14].

2.2 *Exit-to-Exit Highway Automation*

Besides platooning, the main type of automated trucking use case considered today for near-term deployment is the automation of highway driving operations for individual trucks. While, as mentioned above, Level 1–2 automation already exists in many trucks (e.g., ACC, lane keeping assist and their combination), there is a strong focus today on automating exit-to-exit highway operations at higher levels (Levels 3–4). One particular focus today is on Level 4 systems running driverless on highways, starting and stopping at staging areas adjacent to the highway, with trailers being pulled along local roads by human drivers and then switched to the driverless rigs at the staging area. Prior to 2017, Uber Advanced Technology Group (ATG, formerly Otto) was the only truck automation company focusing on Level 4 driverless operations on highways, while major truck OEMs were pursuing in-house development of Level 1 through Level 3 systems to some degree. However, during 2017 at least five new startups focusing on truck automation emerged in the U.S., with several more overseas, and the major truck manufacturers and suppliers amped up their efforts substantially. Examples of companies focusing on realizing Level 4 exit-to-exit operations, strongly supported by venture capital, include Uber ATG, Waymo, Embark, Starsky Robotics, Tesla and TuSimple. Initial deployments are expected to occur in highly constrained operational environments, such as freeways in remote areas with very little non-truck traffic. Current testing of these systems on public roads has been at Level 2, under the continuous supervision of test drivers.

2.3 Off-Road Trucking Automation

Off-road, confined, areas such as mines, ports and terminals offer more benign environments for deploying automated trucking applications than public roads. This section briefly reviews the successful deployment of automated hauling trucks in mines as well as some examples of other trucking automation applications at local sites such as ports and yards.

2.3.1 Mine Hauling

Mine hauling is perhaps the clearest existing example of successful deployment of highly automated trucks. The automated trucking applications are hauling ore and waste from a loading tool to a crusher for processing or to be dumped as waste. The haul distance range from 2 to 7 miles one way. The vehicle configuration is similar to a two axle on highway dump truck with total gross vehicle weights of 700 ton. Automation of these trucks started with trials in the early 1990s with the second generation of trucks going into production around 2007 with Komatsu and Caterpillar in 2013. The main adopter of these automation applications have been the iron ore mines in Western Australia. Shortage of truck drivers created the pull for mining companies to in this region to be first adopters. The economic benefits of the automation have been made public by Fortescue Metals Group and Rio Tinto. The mining companies are achieving a 20% increase in productivity along with a step change reduction in safety incidents. Over the past few years, the mining companies have been developing their processes and people along with mine layout to optimize the implementation of the automation and they have recently announced plans to roll out the technology to significantly greater number of operations.

2.3.2 Manufacturing/Distribution in Dispersed Local Sites

Level 4 automated trucking development is also targeting low speed operations in and around logistics, intermodal, and distribution centers. This may occur purely on private property, for example container movements in ports, "trailer-switching" between trailer storage yards and loading docks, or on short sections of public road, such as between an intermodal facility (rail, ship port, airport) and a nearby container yard. Because the geographic area of operation is quite small, electric propulsion combined with automated driving is considered as a good option. This in turn is motivating the consideration of completely new vehicle platforms, in some cases with no driver cab. Established industry players are somewhat active in this space, having demonstrated prototype systems. Additionally, one startup, Swedish Einride aims to commercialize a custom-designed electric automated freight platform. The ability to use driverless operations for these short runs on public roads preserves driving time for human drivers hauling other loads.

3 Key Deployment Factors

As reviewed in the previous section there exists today a range of automated trucking applications. However, the extent to which these applications will eventually be deployed on a large scale in revenue-producing on-road operations depends on a number of factors including use cases and business models, safety assurance, human factors, regulation, impact on labor, and public acceptance and trust. This section reviews and discusses a set of key deployment factors that were identified at the AVS17 breakout session.

3.1 Use Cases and Business Models

Key factors affecting the trucking industry today include driver shortage, hours of service, fuel cost, crashes, congestion, sustainability, trailer length/longer combination vehicles and increasing home-delivery parcel volumes. Automated driving technologies have the potential to address all of these factors which is a main reason for the large stakeholder interest. In fact, it is commonly suggested that automated driving technologies will be more rapidly deployed for trucks than for passenger vehicles due to the presence of several strong use cases and associated business models with compelling economic benefits.

The potential benefits of automated trucking depend strongly on the specific use cases considered, that is, what aspects of the trucking operations that are being automated. The trucking domain differs fundamentally from the passenger vehicle domain in terms of the general customer needs (and motivation to pay) for automation as well as in terms of the specific operations that are the focus of the automation. While private vehicle customers' decisions to invest in automated driving features may be related to a desire to increase safety, driving comfort and social status, or freeing up time for work or leisure, the key motivation for a trucking company to invest in automated driving functions is to increase the profit margins on its specific transport operations, although safety is always an important motivation as well. Importantly, trucking operations are strongly heterogeneous so some are more suitable for automation than others.

There seems to be a relatively strong consensus among stakeholders today that the greatest short-term potential for automated trucking is in the context of long-haul freight operations on highways. Compared to urban or suburban roads, highways represent a relatively benign (less complex) environment for implementing automation and long-haul trucks spend the vast majority of their time there. Moreover, for long-haul deliveries between hubs, the operations of several trucks may be coordinated which is particularly important for platooning as it allows for efficient formation of platoons. Thus, large private fleets, with homogeneity in their tractor manufacturer and predictable routes, large truckload carriers and less-than-truckload carriers operating long-haul trucks on fixed routes between terminals are likely to be the main early adopters of automated trucking applications [15, p. 29].

Even given a set of strong use cases, the actual deployment of trucking automation will ultimately depend on the existence of detailed *business models* making a sufficiently strong case for trucking companies to invest in these technologies. A key constraint here is that the trucking industry typically operates on small margins, hence expecting a fast and certain return on investments in new technologies. Moreover, the introduction of automated driving technology may impose the need for other investments such as driver/operator training, additional maintenance, etc. It is important to note, however, that if the efficiency, safety and economic returns from truck automation demonstrated in early tests and simulations are realized, it will be difficult for companies that *do not* deploy automation to remain competitive. This could result in very rapid adoption across the industry.

For Level 1–2 platooning, the key factor driving the business case is fuel savings related to aerodynamic drafting, which increase with reduced distance between trucks [7]. For automation of individual, exit-to-exit, truck operations on highways, major benefits would be expected in terms of productivity, safety and reductions in operational costs. These benefits are obviously highest for higher levels of automation (Level 3+) when the technology can partly or completely replace the driver. However, these operations will also incur significant new costs for the staging areas that will be needed for the transitions between manually driven vehicles on local streets and automated operations on the highway. The challenges associated with safety assurance and public acceptance (further discussed below) have led many stakeholders to the conclusion that large driverless trucks are not likely to be deployed on highly occupied public highways in the near future.

Still, significant benefits may be expected even for lower levels of automation. For example, automating part of the long haul operation may allow for less restrictive hours of service regulations, thus potentially increasing productivity. Moreover, lower-level automated trucking applications are expected to yield significant safety benefits beyond those possible to achieve with traditional collision avoidance systems. These safety benefits translate directly to reductions in operational costs related to crashes (a large part of which are related to litigation issues, at least in the US). It is also likely that automation will bring unanticipated economical benefits. For example in the mining domain, a key motivation for introducing automated trucks was to increase the productivity through increased hours of operation, but is it was also found that significant cost savings were obtained through more predictable operations. This predictability has created significant benefits in the mining value stream in addition to the benefit of increased productivity. In the on-road trucking domain, similar benefits from automation may be obtained by supply chain and logistics providers facing a rise of tight delivery windows with penalties for early or late arrival of goods.

To summarize, deployment of automated trucking features will depend critically on the identification of specific use cases tailored to the needs of individual carriers, and business models promising a significant and fast return on investment.

3.2 Safety Assurance

The safety assurance of automated driving technologies is viewed by all stakeholders as a key deployment factor, especially for higher levels of automation. Brand trust is equally important to vehicle manufacturers, carriers and their shipping clients, so public perception is critical and everyone agrees that safety cannot be compromised for economic savings. The key issue is thus how one can ensure that automated driving applications are safe enough and able to address all the possible edge cases that they may encounter. Indeed, safety assurance turned out to be the most challenging issue in the development of mine hauling automation, accounting for the lion's share of the development costs.

Thus, vehicle manufacturers, suppliers and tech companies need to work together to ensure the safety of automation applications by means of simulation, track tests and on-road field tests. There are also a number of specific safety assurance issues that need to be addressed for platooning, such as how to deal with different braking capabilities of the vehicles in the platoon. There is today a strong focus on the development of novel data collection, testing and simulation methodologies to address these issues.

3.3 Human Factors

There is a range of human factors-related issues that are expected to strongly influence the deployment of trucking automation. These range from the individual driver/operator's understanding of and interaction with the automation, to higher level organizational issues related to the potentially changing roles of the workforce, new decision structures and needs for additional education and training. See [16] for a general overview of human factors issues in automation.

3.4 Regulation

In the US, there is today a patchwork of state laws governing truck operations and automated vehicles. As of January 2018, 21 states have enacted automated vehicle laws and six states have chosen to use executive orders to outline a policy for automated driving. For example, the allowable following distance for trucks is dealt with differently in different states. Hence, increased harmonization is needed, even more so for automated trucks than for passenger cars since trucks are more likely to cross (national and state) borders and are thus susceptible to multiple regulatory frameworks applying to a single trip. However, it should be noted that at least some of these issues (such as differences in minimum allowed following distances) may be possible to solve by technological means (e.g., by adapting the following distances in the platoon when crossing the border).

Current US Federal Motor Vehicle Safety Standards (FMVSS) regulations assume the presence of a driver and may thus be a barrier to novel designs. The House passed a bill in 2017 to increase the FMVSS exemption caps from 2500 units to 100,000 units, which would allow manufacturers to produce novel designs for higher levels of automation, although they would still need to demonstrate that the designs are no less safe than an FMVSS-compliant design. The FMCSA hours of service regulations, security and privacy are other key regulatory areas that may need to be addressed with the emergence of automated trucking.

Existing regulations can accommodate AV technologies up to a point, but this becomes increasingly challenging when moving towards higher levels of automation. Industry generally prefers adapting existing regulations over creating new frameworks locking in a standard that is too high or too low. However, stretching existing regulatory frameworks has its disadvantages and limits and unintended consequences are likely since the regulation was not originally intended for automated trucks.

A recent study [17] has shown that there is considerable potential for a completely new, data-driven, regulatory framework. Current rules and regulations in road freight transport could be replaced by quantifiable policy indicators complemented by the use of data from multiple sources allowing the analysis of stakeholders' alignment with policy objectives and compliance with regulations in near-real time.

3.5 Public Acceptance and Trust

Public acceptance of, and trust in, automated driving technologies remains a key deployment challenge which would be expected to be particularly pronounced for large trucks operating on public roads.

There is general consensus among stakeholders that educational campaigns will be important to foster public acceptance of automated trucking technologies. In particular, it is important to convey a nuanced view and focus on explaining the benefits of AV technologies to the public and openly providing accurate data to support safety claims. Public demonstrations are also seen as good ways to raise public awareness and gain acceptance.

3.6 Impact on Labor

According to the Bureau of Labor Statistics (BLS), there are almost three million truck drivers in the US [18] and there is a worry that trucking automation will create a disruptive loss of jobs in the trucking industry. For example, a recent ITF-OECD Roundtable workshop [19] suggested that job losses in the order of one million people in each of Europe and North America are possible as a result of advanced automated driving technology.

However, at the same time, a major problem in the trucking industry today is the shortage of drivers. Moreover, for reasons discussed above (in particular the challenges associated with safety assurance and public acceptance) many industrial stakeholders do not expect a disruptive introduction of highly automated trucks in the foreseeable future. Hence, these stakeholders argue that automated trucking will most likely not have any dramatic impact on labor, at least not in the short term and with the current generation of drivers. A further reason for this is that large truckload carriers today typically have a turnover rate for drivers of 70–80%. It may be argued that automated driving technologies could offer an improved working environment for drivers in large long haul fleets, thus making the job more attractive and helping to counter driver attrition, as well as attracting a new class of driver in the next generation. Even at higher levels of automation, an operator might still need to be present in the vehicle for, e.g., high-level system supervision, deliveries, or carrying out the manual driving tasks in parts of the network where automated operation is not possible. Clear communication from fleets and vehicle/systems manufacturers on how the deployment of future automated trucking applications is expected to play out will be of key importance for addressing resistance from employees, unions and other associations that may be threatened by these developments.

4 Roads to Deployment

Given the different factors reviewed in the previous section, what is the best approach for moving beyond technology demonstrations towards actual industrial deployment of automated trucking applications?

Based on the discussion at the breakout session, a useful starting point is that what is being automated is not just the trucks themselves but the specific transport *operations* for which the trucks are being used. This is also consistent with lessons learned from the mining domain described earlier. An example of such a specific operation discussed in the breakout session was delivery of refrigerated food items to restaurants. If significant efficiency gains can be realized from automation of hauling, then new food items may be possible to transport due to shorter shipping times and reduction of spoilage. From this perspective, the first step for the manufacturer of an automated trucking application is to understand in detail the specific operations that the automation is intended to address. A key challenge here is that trucking operations are typically heterogeneous and idiosyncratic. In addition, the multitude of factors reviewed above makes deployment of automation a multidimensional problem, where certain issues (e.g., regulation, organizational change) may be critical in some types of operations, for certain types of carriers, but not for others.

Thus, to manage this complexity, it may be suggested that deployment of automated driving functions is best conducted in a stepwise, iterative, fashion, starting with one or a few trucks performing automated operations in revenue-producing conditions. This way, carriers could evaluate specific deployment factors such as potential cost savings, the need for additional investments (e.g., for driver training and education) and safety assurance on a smaller scale and feed back to the own organization as well as to the vehicle/technology manufacturers. Such stepwise, incremental, trials could also be used to foster public acceptance and the data collected could be used as an important input to regulation, particularly in view of data-driven regulatory approaches discussed above.

This further suggests that strategic partnerships between key stakeholders, including carriers, their clients, traditional truck manufacturers, new tech companies and road authorities will become very important for effective deployment of trucking automation applications. These partnerships may potentially also include other players that may add to the business models such as insurance companies.

5 Conclusions

This chapter provided a discussion of current factors influencing the deployment of trucking automation based on the discussions among experts and key stakeholders at the AVS17 trucking automation breakout session. Automated trucking applications have the potential to address many of the key challenges that the trucking industry faces today and there is a very strong interest among different stakeholders, with several new players entering the field.

Off road, closed-course automated trucking applications already exist, in particular for mine hauling and container terminals, and important lessons can be learned from these domains when embarking on trucking automation for public roads. The main current focus for on-road automation applications is on platooning (at different automation levels) and exit-to-exit highway automation.

A number of key deployment issues were discussed. The importance of understanding the specific transport operations and associated use cases and business models for automation was emphasized. Safety assurance (ensuring the automation is able to safely handle all eventualities, or edge cases) is a key constraining factor and human factors issues, including the organizational level, need to be carefully considered. Regulation, in particular harmonization between states and countries, is particularly important for trucking, since trucks are crossing borders more than passenger vehicles. Negative impacts on labor in terms of job loss for truck drivers is often suggested as a major potential societal problem associated with automated trucking. However, stakeholders are divided on how disruptive these effects will actually be. Finally public acceptance of, and trust in, automated trucks is clearly an important prerequisite for large-scale deployment.

Since the return on investment from automation depends critically on the specific type of operations to be automated, it is critical for automated technology manufacturers to know their customers and their specific operations in detail when deploying automated trucking applications. The fact that the significance of the various deployment factors (e.g., safety assurance, human factors, regulation) may differ for different types of automation, and different types of operations makes trucking automation deployment a complex problem and this can be seen as the main reason why the future of automated trucking is so hard to predict. On the other hand, if large scale efficiencies, safety and economic benefits predicted by current trials are realized in operations, there may be a hockey stick adoption of trucking automation since laggards will find themselves uncompetitive in this new environment. These challenges and opportunities are part of what makes the field of automated trucking so fascinating.

It was suggested that, in order to manage this complexity, a likely road to deployment is the formation of strategic partnerships between key stakeholders which can evaluate the business models and address other deployment issues in an incremental fashion, starting out small, but still in a realistic revenue-producing environment.

Perhaps the most important take-away from the AVS17 trucking breakout session is that there seems to be a universal will amongst key players to make automated trucking a reality. However, it remains to be seen how it all will play out in the end and what will be the best way to get there. AVS18 will be held July 9–12, again in San Francisco.

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The Road Ahead—How a 100-Year Old Mobility Service Transforms into a World of Automated Driving

Suna Taymaz

Abstract Automobile clubs like AAA were often established in the early days of the automobile and have served its Members well over the decades with mobility related services such as roadside assistance, insurance, travel, and other related products. Now 100 years later, the question arises how such a well-established mobility service with a trusted brand can evolve into a world of automated vehicles when also car ownership might be a thing of the past. A closer look at this situation shows that especially with increasing automation of the vehicle, consumer education along with safety advocacy and related mobility options are needed as ever before. The mission is to make sure that the transition of mobility stays consumer oriented and safety focused. With the complexity of the mobility sector further increasing, partnerships will be key to fulfill this mission.

Keywords AAA · Autonomous driving · Automated driving · Mobility as a service · Transportation as a service · Insurance · Roadside assistance Consumer · Connectivity · Safety

1 Introduction

The American Automobile Association (AAA) has a long history of supporting its Members in their mobility needs. Founded at the beginning of the 1900s with the premise to advocate safe and responsible transportation, it is today a federation of about 30 clubs in the United States and has partnered with about 60 other similar organizations worldwide. The geographically largest U.S. club is AAA NCNU, serves one in every five Californians, and 60+ million Members U.S. wide. With

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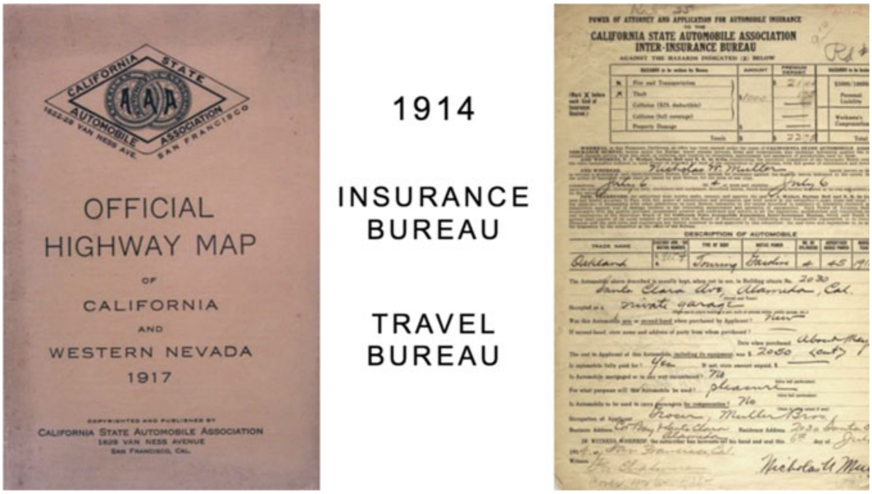

Fig. 1 Mobility service offerings in the early 1900s—highway map and vehicle insurance

such a broad reach, AAA NCNU sees itself highly committed to its Members, to which it primarily offers roadside assistance and insurance that have been strong pillars from the beginning (Fig. 1). In addition, through its National Foundation for Traffic Safety, the club conducts research on emerging automotive technologies, roadway systems, and consumer perception and government interaction to make sure transportation remains safe, reliable, and convenient while the landscape evolves. With this mission, AAA NCNU has also pioneered mobility products like ride-sharing (1940s), live traffic information (1960s), and online registration renewal (2000s).

With this history, mission, and current product portfolio in mind, the question arises what the role of an automobile club in a world of automated vehicles will be, and even more once those vehicles might become completely driverless and shared. Who will be interested in car insurance and roadside assistance in a world where consumers do not drive themselves and also do not own a vehicle anymore? Despite the assumption that this ultimate scenario will take probably several decades to become a ubiquitous reality [1], an organization like AAA NCNU should plan ahead and actually become a driver of change rather than a reactor. With a primary goal as a mutual benefit non-profit organization that exists to serve its Members, AAA must be ready for the change in transportation, whether it occurs today or several decades from now. The following will discuss in detail the role that a membership-driven automobile club can—and probably should—play as a mobility service in the evolving field of automated driving.

2 Changing Mobility

Mobility is changing rapidly today and with that the automobile is changing as well. This change is largely driven by disruptive trends, which actually turn the automotive industry into a mobility marketplace:

- Car ownership: 30% of Millennials do not plan to purchase a car in the near future
- The average car is in motion for only 60 min per day
- The car sharing and ride sharing market is predicted to exceed $30B by 2024.

In parallel to those trends, the need for road service has decreased for the last 4 decades as vehicle technology has advanced. That is a testament for increased vehicle reliability, which is expected to continue to improve.

Despite the increased reliability, the automobile is changing in its entirety and with that the industry is set for much upheaval. Mary Barra, CEO of General Motors, is often quoted with her statement "… the industry will experience more change in the next 5 years than it has in the last 50 years" [2]. This statement is largely aimed at the change that the automobile will become increasingly:

- Autonomous—eventually will be self-driving
- Connected—connected to one another and to infrastructure
- Electric—powered by electricity instead of fossil fuels
- Shared—centrally owned and only rented for the time needed

At the same time, consumers have concerns about those trends, in particular the autonomous vehicle, as an AAA survey [3] found in March 2017:

- 78% of U.S. drivers would be afraid to ride in a self-driving vehicle
- 54% would feel less safe sharing the road with self-driving cars
- 59% want autonomous technology in the next vehicle they buy or lease
- only 16% of motorists would trust a vehicle from a technology company

The latest AAA survey published in January 2018 shows actually that consumers are warming up to the idea of self-driving vehicles [4]. 63% of U.S. drivers would now be afraid to ride in one (down from 78% in 2017), and 46% would feel less safe sharing the road with one (down from 54% in 2017). Those statistics and trends show the need for consumer education, increased transparency on safety, and a better understanding of the autonomous vehicle's operating conditions (Operating Design Domain), which are now also outlined by the U.S. Department of Transportation in light of the safety guidelines for automated vehicles [5]. In addition, the trends also characterize the future of mobility much more as a service than it might have been in the past, and often formulations like Transportation as a

Service (TaaS) are used to describe what mobility will be like going forward. The hypothesis, then, is how a century-old mobility service player can help bring TaaS to its 60 million + U.S. Members, helping to transform the transportation economy while necessarily disrupting its business as it exists today. Indeed, this very transformation is AAA's legacy and "origin story", disrupting the horse and buggy with automotive vehicles over a century ago.

3 The Role of a Mobility Service Player in Automation

Given the evolution toward autonomous, connected, electric, and shared vehicles, the role of a mobility service player like AAA is depicted in Fig. 2. With AAA's commitment to consumer advocacy and safety, the interaction with regulators as

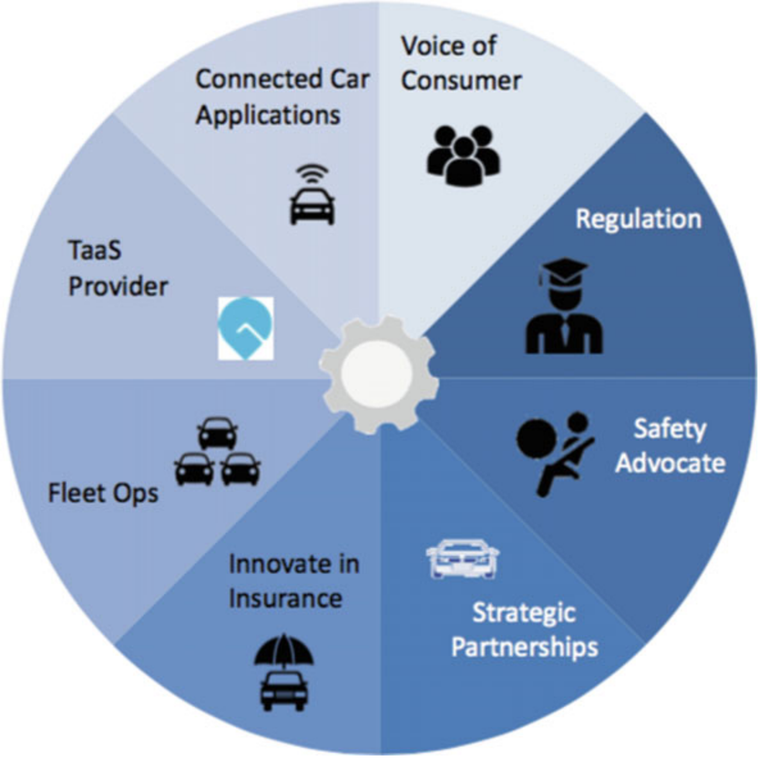

Fig. 2 The evolving role of a mobility service player in a world of autonomous, connected, electric, shared vehicles

well as manufacturers will be as important as ever to ensure timely consumer information, education and ultimately innovative products that enrich the lives of AAA's Members.

For automated driving this means that an independent and trusted player is needed to be outspoken about safety requirements and define standards for certification, operation, and maintenance of automated vehicles. At present, it is still unclear, for instance, how safety for automated vehicles should be measured. There is no agreed standard to determine the performance as well as respective measures needed to meet safety requirements. However, as consumers are largely concerned about automated vehicles and at the same time the industry is moving quickly toward deployment, first in pilot tests and with increasing levels of automation, such safety requirements need to be established, respective product performance tested, and results communicated. This is even more applicable as the vehicle manufacturers would also benefit from consensus and certainty on the testing "goalpost" in the form of benchmarks, criteria, or standards.

Such an independent and trusted player for safety advocacy also has to build partnerships with industry to stay abreast of the development of automated driving technology and also to jointly develop standards. An established, third party and technology-neutral mobility service player focused on safety is well suited in such a partnership, as there is long-lasting expertise in automotive and mobility as well as impartiality.

The products a mobility service provider can contribute to the evolving mobility sector are fleet operations, TaaS offerings, and also connectivity products. For instance there are opportunities to serve as an aggregator for different mobility services (car sharing, rental car, public transportation…), vehicle related apps (safe/efficient driving suggestions, vehicle diagnostics…), or peer products (ride sharing, vehicle reviews, travel support…). The role of a neutral player is becoming increasingly important in those applications and in particular for automated vehicles to focus on consumer needs and uncompromised safety with this accelerated transition in mobility.

4 Summary and Outlook for Mobility Services in a World of Automated Driving

While it is nearly impossible at this point to predict what future mobility models and preferences will look like, services will play a key role in consumers' choice and product differentiation [6–8]. That means whatever the use case or opportunity, the consumer adoption "table stakes" framework will begin with safety, cost, reliability, and convenience, as a base to then offer further differentiated services. In fact, these qualities are where AAA's roadside service has consistently outperformed, resulting in 90% percentile satisfaction ratings from its Members. As it was discussed, an independent player should advocate for the needs of the consumer while providing neutral and "spin-free" education on promising new technologies and services. Therefore partnerships with the supply side of the mobility economy need to be established, which for now would be vehicle manufacturers and direct services (car/ride sharing etc.), but also tech and media companies that function more and more as cross-boundary providers of an end-to-end customer experience that includes mobility.

In this world of ubiquitously connected and fully automated driving, the role of a consumer and safety advocate will be more important than ever as product offerings will be even harder to understand and ascertain for consumers. However, serving consumers as a neutral advocate also requires understanding and actually shaping this world of connected and automated driving, and learning what are the shifting needs of AAA's membership base from over a century ago when the association were founded.

AAA's unique position as a membership organization means that it is driven by providing value to its Members spend. The question to be asked is how this value is generated in a world where many services are expected to be free or at least offered at a very low cost. Information, communication, and energy are such examples, and mobility as a service might evolve to fall into the same category. This means that revenue models will also shift from direct consumer monetary transactions to indirect transactions such as data as a currency, advertising, or licenses. The transactions must also be trustworthy and protect security or offer privacy options. While not all of this can be imagined today, such players need to be open to not only innovate products but establish new monetization strategies as well [9].

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Automated Vehicles Cybersecurity: Summary AVS'17 and Stakeholder Analysis

Jonathan Petit

Abstract The security of Automated Vehicles (AVs) should be addressed to prevent and mitigate cyber-attacks. This includes securing the vehicle itself, and the supporting infrastructure. Securing the ecosystem requires multitude of security controls and privacy enhanced techniques. However, stakeholders do not have sufficient resources to cover everything. Therefore, where to start is often context-dependent and based on a thorough risk assessment of the ecosystem. In this chapter, we first summarize the discussions around cybersecurity at the Automated Vehicles Symposium 2017, and then present a stakeholder analysis to guide them in their cybersecurity effort.

Keywords Cybersecurity · Stakeholder analysis · Automated vehicle
Intelligent transportation systems

1 Summary from the Automated Vehicles Symposium 2017

At the Automated Vehicles Symposium 2017 (AVS'17), we addressed a plenary talk to the $\sim$1500 attendees, stating that even though it is unanimously considered as paramount, cybersecurity is still an after-thought. Or at least it still feels like it. Indeed, for the last two AVS editions, the cybersecurity breakout session reported similar open challenges, but no real changes have been seen since. In order to move the security needle, we took a different approach and didn't organize a cybersecurity breakout session. Instead, we identified that the missing components were the lack of inputs coming from the community of experts. To be able to build a more resilient system, cybersecurity experts should know about the limitations of each subsystem, and possible "nightmare scenarios".

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To kick off the discussion, we developed questions for each of the 25 breakout sessions (see http://www.automatedvehiclessymposium.org/program/2017-speakers/jpetit for Excel format of Table 1 below). Attendees could read and ponder the questions before sharing their thoughts with us in the breakout sessions.

Table 1 List of questions for each breakout session at AVS'17

Break-out #	Name	Security-related question(s)
1	Research To Examine Behavioral Responses to AVs	n/a
2.1	Judging a Car by its Cover: Human Factors Implications for Automated Vehicle External Communication	How does attack impact user (reaction, acceptance)? How to re-engage user to mitigate ongoing attack?
2.3	Automated Vehicle Challenges: How can Human Factors Research Help Inform Designers, Road Users, and Policy Makers?	see 2.1
3	Enabling Technologies for Automated Vehicles	How to certify cybersecurity in new technologies?
4	An AV Crashes: What Happens Next?	How to ensure chain of custody of data and detect tampering? How is cybersecurity integrated in forensics processes after crash?
5	Public Transport and Shared Mobility	Does public transport have higher security and privacy requirements because of greater consequence of attack? Is privacy a concern in case of shared mobility?
6	Trucking Automation: Key Deployment Scenarios	How can attacker interfere with truck platooning? How vulnerable is a truck during its different phases on the supply chain? What makes truck unique compared to personal AV?
7	Enterprise Solutions Series	n/a
8	Urbanism Next Workshop: AV's Effects on Urban Development	How can privacy or security could be integrated in the urban development (e.g. privacy-preserving road network)?
9	Effects of Vehicle Automation on Energy-Usage and Emissions	What can an attacker do to affect energy-usage or emissions (e.g. force vehicles to use longer path, deadlock)? Can AV be used as "entry point" to smart grid? Can large scale attack impact the overall energy demand and thus pricing?
10	Data Sharing Models and Policy	Who should be allowed to collect data and share it? How to control data sharing? Do data sharing models offer

(continued)

Table 1 (continued)

Break-out #	Name	Security-related question(s)
		opt-in/opt-out and privacy notification to user? Where is the data analysis/ sanitization done?
11	Artificial Intelligence (AI) and Machine Learning (ML) for Automated Vehicles (AV): Exploring Tools, Algorithms, and Emerging Issues	How can AI/ML be attacked? What is the most valuable algorithm/data (i.e. this will be the main target of attacker)? What are the conditions in which the AI/ML techniques don't perform as efficiently? DNN can be fooled, classifier stolen, how do you consider this in your design?
12	Testing Connected and Automated Vehicles (CAVs): Accelerating Innovation, Integration, Deployment and Sharing Results	Security testing should be part of the functional testing? Where would it fit?
13	Challenges and Opportunities for the Intersection of Vulnerable Road Users (VRU) and AVs	How do you differentiate VRU from regular users? This differentiation could enable tracking of VRU so it should be thought carefully. Do VRU have special "feature" when interacting with AV or the infrastructure?
14	Enhancing the Validity of Traffic Flow Models with Emerging Data	How to identify "spoiled" data to ensure quality of the models? How to use misbehavior detection/anomaly detection to enhance validity of models? What emerging data are you using? Can we use similar traffic flow model in cybersecurity to improve detection of attacks?
15	CAV Scenarios for High-Speed, Controlled Access Facilities	How can attacker block entrance to controlled access facilities? How is access control/authentication performed?
16	Aftermarket Systems (ADAS- related)	Where/How are aftermarket systems connected to the vehicle? What information are collected by the aftermarket devices? Have you performed a threat analysis of the aftermarket devices?
17	Safety Assurance	Security vulnerability could lead to safety issue. Is security included in the safety assurance? How to assure that attacks won't affect safety?
18	Reading the Road Ahead: Infrastructure Readiness	What are the most important infrastructure requirements to enable AV operation? How to protect the

(continued)

Table 1 (continued)

Break-out #	Name	Security-related question(s)
		infrastructure against malicious manipulation?
21	Connected and Automated Vehicles in Traffic Signal Systems	How do you protect the ITS Roadside Equipment or TMC from malicious input coming from RSU or AV? Is that only an unidirectional communication or do the traffic signal systems take input (e.g. use data) from end entities (e.g. AV, RSU, VRU)?
22	Legal and Policy Approaches: Finding the Right Balance on Legislating for Automated Vehicles	Legislation of security and privacy protection techniques: what should be legal or technical solution? What is the status of security and privacy legislation?
23	Connected Automated Vehicle Early Deployment Alternatives	n/a
24	Automated Vehicles for People with Disabilities	see 13
25	Ethical and Social Implications	Do you think cyberattacks should be “punished” in order to deter “bad” social behaviors?

We received the following inputs from participants:

1. Human Factors:

Some people ignore security patches, making their vehicles vulnerable to attacks. If the updates are not installed at a time the vehicle is not in operation, it is likely that the installation will not happen, thus making the vehicle vulnerable. But while not installing a patch on a desktop compromises information, not installing a patch on a vehicle could lead to a failure of the vehicle to operate properly putting the driver and other road users in danger. This problem is even greater in autonomous vehicles.

2. Public transportation:

Attendees concerned about public transportation systems voiced several concerns. They were worried about potential end-user vulnerabilities to financial attack through false delivery of service. They wondered how 3rd party organizations could provide accurate “ground-truthing” data for the public transportation infrastructure. And they wanted advice on how public transportation could incentivize pro-active penetration/security testing by the white hat hacker community.

3. Sensor fusion:

One participant proposed a robust sensor fusion technique in which two parallel encrypted systems fuse sensor data with two different algorithms that should output the same result. Any inconsistencies between the two sensor fusion systems would trigger an alert that the system might have been compromised. Another approach is to use two sets of sensors that use different technology and compensating features in order to detect attacks on sensors.

4. Automated heavy vehicles:

Truck makers are very concerned about the impact of attacks. One respondent said, "If semi-autonomous trucks can be hacked enough to stop them, a road could be blocked, a city disrupted, or the economy shut down. More even than cars, trucks pose a big threat."

5. Actuators security:

"The real danger for autonomous vehicles does not come from the sensor data, but from all the actuators that are accessible from the car's computers," voiced one engineer. "However, there may be simple ways to harden them against hacking. For example, before putting any actuator into automated mode, check the state of the HMI and a recent history of driver inputs to it."

After I gave the summary report, one attendee from the trucking industry shared his nightmare scenario. Imagine that it is 6 AM on a busy urban highway. Hackers cause a fleet of trucks to crash into each other, blocking the highway for an extended period of time as authorities untangle the wreckage. The entire time, news reports broadcast the wreckage and resulting traffic disruption with the name of his company prominently displayed for the world to see. This is exactly what was the call for input about! From his example, we learn that the timing component is important and the impact on branding too. This helps us frame a realistic attacker model to improve the risk assessment.

Despites the low number of responses, cybersecurity-related discussions identified the need to perform a stakeholder analysis in order to frame the solution. In the following Sections, we provide a non-extensive analysis that should serve as a baseline for further study.

2 System Model

Figure 1 shows the Connected and Automated Vehicles (CAV) ecosystem. The sensors in (b) Fig. 1 sense the environment (a) (e.g. road sign, lane marking, object). Then, the sensor data is processed by the processing unit (c) (sometimes included in the sensor) before being potentially stored (d) to build local dynamic maps (e). The system relies on networks (f) [e.g. in-vehicle, cloud (g), vehicle-to-x (h)] to convey information between sensors and processing unit or to external entity [e.g. roadside unit, neighboring vehicles, traffic management control (i)].

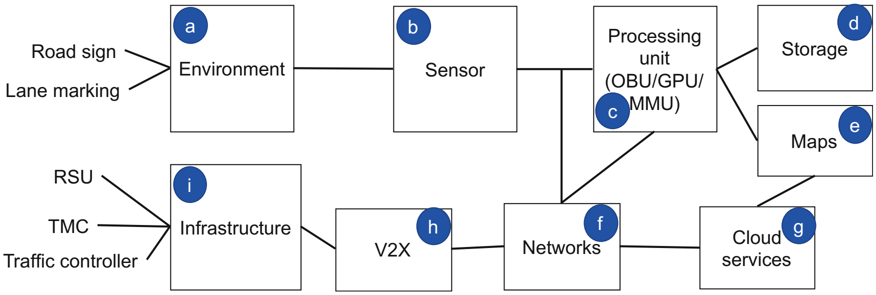

Fig. 1 Connected and automated vehicles ecosystem

To ensure the CAV ecosystem's security, every component needs to be secured. However, as discussed in the next Section, the threat assessment depends on the stakeholder being considered. It will take a global and coordinated effort to secure effectively the CAV ecosystem.

3 Stakeholder Analysis

The stakeholder analysis aims to highlight the trends and challenges in security that CAV stakeholders face. Using the system model depicted in Fig. 1, we discuss where the priority should be for each stakeholder. For example, road operators should focus on securing the infrastructure they manage (e.g. traffic controllers, Roadside Units (RSUs), camera network, Traffic Management Center), and the data collected. In the context of Connected Vehicles (CV), road operators will collect Basic Safety Messages [1] from RSUs in order to perform dynamic traffic management. This Section does not pretend to provide a complete stakeholder analysis, but should serve as pointers for stakeholders. In the following, we will present the security challenges for: sensor suppliers, processing unit suppliers, road operators, users (focusing on fleet operators), and Cloud service providers.

3.1 Sensor Supplier

From Fig. 1 it is clear that sensor manufacturers should protect the sensors (and its processing unit if integrated within the sensor). The sensor manufacturers should also consider malicious environmental perturbations and try to make the sensors smarter (active in-depth defense system). The sensor should identify poor performances (due do miscalibration or attack), adjust its functioning if possible (e.g. frequency-hopping random chirp FMCW technique used in some RADAR), and give a confidence value that reflects its current operational environment.

The first step in securing the sensors is to perform a risk assessment/penetration testing. This analysis would assess the sophistication of the attacks, the resources required to perform them, and their scalability. One indirect benefit from a threat assessment is that on top of a better understanding of risk, it highlights solutions to improve resilience. Therefore, every sensor (even the smallest ones) should go through a threat assessment. For example, a threat model of accelerometers used in airbag ECUs would demonstrate that an audio signal could excite the accelerometer and put it in resonance frequency [2], thus becoming an attack surface to inappropriately trigger airbags. Hence, the system requirements such as *shielding* would be adjusted accordingly.

At the sensor level, one challenge is to differentiate transient faults from attacks, and remote attacks from attacks with physical access (e.g. side channel attack). One technique to hamper physical access and data manipulation (e.g. infiltration, exfiltration) is to build tamper-resistance. Another technique is access control and authentication. However, authentication requires to store cryptographic material securely (often in Hardware Security Module) to perform some cryptographic operations (e.g. digital signature generation, signature verification), which could be challenging for constrained sensors.

Because the aforementioned prevention and detection techniques are not bulletproof, a recovery action could be to update the sensor's firmware. Hence, this would require the deployment of secure firmware over-the-air update solution.[1]

3.2 Processing Unit Supplier

Processing unit suppliers share similar security challenges as sensor suppliers. For example, side channel resistance of On Board Unit or Electronic Control Unit is needed. To prevent theft of cryptographic material, private keys are stored within a Hardware Security Module (HSM). A research challenge is to analyze side-channel resistance of HSM to verify that keys cannot be extracted.

As a processing unit can be seen as an embedded computer, it faces similar security threats, which require host-based security. Therefore, processing unit suppliers should investigate host-based intrusion detection system, secure boot, secure operating system (potentially formally verified), or formally verified parser, in order to minimize effects of attacks that would degrade performances otherwise.

As for sensor suppliers, secure software over-the-air update is a key technology to adapt the security controls to the ever-changing threat landscape.

The processing unit is in charge of data management (i.e. calling storage functions), and should be able to control and audit access to data (i.e. which processes read/write data) to protect against data theft. Another approach is to

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[1] Firmware Over-The-Air (FOTA) update is an open challenge. Interested readers are encouraged to check the DHS funded project UPTANE (https://uptane.github.io).

encrypt the data and rely on private information retrieval (PIR) [3]. PIR performs all read/write operations in the encrypted domain (i.e. the queries are encrypted and the database too), which would deter data theft. However, one challenge of PIR is to reduce its overhead to make it practical in the automotive industry.

3.3 Road Operator

The road operator is in charge of managing road infrastructure, such as road surface, delineation, or traffic signs, to ensure road safety. Thus, in Fig. 1, it should secure the environment (a) and the infrastructure (i).

One common best practice is to develop a security management operational concept [4]. This document specifies the security controls to deploy, and lays down incident response procedures.

One objective for the road operator is to be able to detect modifications of road infrastructure, either by its own crew or by collecting misbehavior reports generated by users' vehicles (one should note that the latter could be a new attack vector), and this with a low false positive rate.

A road operator could also leverage existing video surveillance system (commonly used to detect anomalies in traffic flow) by mapping the output of image processing (e.g. object detection and classification) with received misbehavior report. These techniques mostly cover the *detect* aspect of a security system.[2] As a response to the detection, one could envision RSUs to broadcast "out of operational design domain[3]" messages wirelessly to CAVs in order to warn that the infrastructure cannot fully support the operation of CAVs at the moment.

3.4 User: Fleet Operator

A fleet operator is in charge of the maintenance and operation of fleet vehicles. Examples of fleet operator are truck companies, delivery service companies, State Police, U.S. General Services Administration, or Mobility-as-a-Service providers.

The introduction of new technologies such as Dedicated Short Range Communication (DSRC), telematics unit, partial or full automation, or electric vehicles, create potential cybersecurity risks for fleet operators. Fleet operators must be educated to the risks in order to ensure suitable procurement and prepare a response plan (i.e. resilience plan for system recovery).

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[2] NIST Cybersecurity framework specifies "identify—protect—detect—respond—recover" (see https://www.nist.gov/cyberframework).

[3] NHTSA specified Operational Design Domains (ODD) as "the specific conditions under which a given [CAV] or feature is intended to function." (see https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/13069a-ads2.0_090617_v9a_tag.pdf).

A Fleet can be composed by ground, aerial, or maritime vehicles, each having different threat models. In the context of government fleet, vehicles can be seen as entry points to reach other critical cyber-physical systems, such as smart grid or operation center, if the vehicle is electric or upload telematics data respectively. Moreover, to support these new technologies, new components (e.g. RSU, Security Credential Management System) will have to be connected to the existing infrastructure (e.g. TMC, traffic controller). This could create attack surfaces not envisioned in the legacy systems (similarly to what happen when SCADA networks got connected to the Internet). Therefore, the first action is to perform a threat assessment to define the minimum security controls to deploy.

One should note that if the fleet is the only one to be equipped with one communication technology, then fleet vehicles will stand out from the crowd, which could particularly be problematic when considering state police vehicles (especially undercover cars). In the context of CV (e.g. DSRC-based and/or cellular-based), location tracking can lead to driver profile (which could be an issue for delivery service for example [5]).

When dealing with Level 4–5 AVs, a fleet operator will require remote control of the vehicle in order to resolve deadlocks. This is critical to secure such capabilities as successful attacks would give the highest privilege (except if the system has multiple level access control, e.g. partial control, full control but with short time window). For example, gaining remote control would allow attackers to access to the sound system (to talk to users), sensor data (internal/external camera, etc.), user data (banking information (for refund), destination), event-data recorder (for debugging). Such attack is attractive because could be highly scalable (e.g. installation of malware on entire fleet and triggered simultaneously).

As mentioned earlier, fleet operator will need access to vehicle (actionable) data for: (i) insurance, (ii) resource allocation, (iii) logging/auditing, (iv) forensics, (v) fleet health monitoring. Therefore, it requires a Data Privacy Plan and Data Management Plan that discuss collection of data, data type, data retention, data disclosure, data aggregation, etc.

As actionable data come from vehicle' sensors, it is plausible that attacks aiming at degrading sensor data could poison the local dynamic map [6, 7], and hence, feed wrong data to the management center and resulting in system disturbance. Therefore, fleet operator should question the security of the sensor itself: is a debug port present and how is it accessed? How to verify the absence of hardware Trojan? How to secure the entire supply chain (where are each component manufactured?—especially important when dealing with government vehicles)? As detecting hardware Trojan isn't trivial, the system should offer fail-safe modes in case sensors get compromised (but detecting compromise is another research challenge).

Finally, another open challenge is certification. To help fleet operator in procurement a cybersecurity "rating" that ensures the product delivers appropriate level of security. To do so, certification laboratories will need cybersecurity test suites along with attack dictionary.

Table 2. Security focus for each stakeholder

Component	Stakeholder				
	Sensor supplier	Proc. unit supplier	Road operator	Fleet operator	Cloud service provider
Environment	✖	✖	●	✖	✖
Sensor	●	○	○	○	✖
Processing unit	○	●	○	○	✖
Storage	✖	●	✖	○	✖
Maps	✖	○	✖	○	○
Cloud service	✖	✖	✖	●	●
Network	○	○	○	○	●
V2X	✖	○	○	●	○
Infrastructure	✖	✖	●	○	✖

3.5 Cloud Service Provider

Cloud services are pervasive to all stakeholders, either for SOTA update, key management system, data collection, fleet management, billing, maps distribution, or many more. Securing cloud services is paramount but is known to be hard. The NIST SP-500-291 Section 6.5 [8] highlights security challenges for cloud service providers.

3.6 Summary

Table 2 summarizes the security focus for each stakeholder. The symbol '●' means the stakeholder should take immediate action to secure this component. The symbol '○' means it is likely an area of focus if the component is used. The symbol '✖' means that the component is not a primary security concern for the stakeholder. One could note that the fleet operator has the most security challenges as it relies on most of the components to perform its mission. This does not mean that the fleet operator should secure the whole chain, but it should pay attention to the security threats of most of the components and push down its requirements to the suppliers.

4 Conclusion

In this Chapter we presented the results of the cybersecurity effort performed at the Automated Vehicles Symposium 2017 and a draft stakeholder analysis. Security challenges are acknowledged by everyone involved in connected and automated vehicles but too little has been done so far. The reasons are a lack of understanding of the threats, the complexity of adding security with minimal overhead, and the need of collaboration between multi-disciplinary experts (e.g. AI, security, human factors). At AVS'18, a cybersecurity breakout session will be organized and will focus on some key questions (not necessarily answered in this chapter): vehicle security, human factors and cybersecurity, resilience, counter machine learning, and infrastructure security.

The stakeholder analysis is an attempt to help stakeholders to kick start or focus their security effort. It should serve as a foundation and should be further developed by being more specific about the security requirements and security controls. One important future work for this analysis is to investigate the interoperability and consistency of the security controls deployed by different stakeholders in order to secure the entire ecosystem.

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Part IV

Vehicle Systems and Technologies Development

PEGASUS—First Steps for the Safe Introduction of Automated Driving

Hermann Winner, Karsten Lemmer, Thomas Form and Jens Mazzega

Abstract PEGASUS (Project for the Establishment of Generally Accepted Quality Criteria, Tools and Methods as well as Scenarios and Situations for the Release of Highly Automated Driving Functions) is a joint project funded by the German Federal Ministry for Economic Affairs and Energy (BMWi) which seeks to close the gaps in the testing and release of automated vehicles (see Fig. 1) and supports the rapid transfer of existing functions and prototypes into series production (Fig. 2). PEGASUS intends to answer these central questions. What is the minimum performance level for an automated vehicle? How do human beings perform (as a reference value)? What can and must automation deliver (and what not)? How can it be demonstrated that the automated vehicle performs reliably?

Keywords Automated driving · Testing · Quality criteria · Tools and methods
Scenarios and situations · Release of highly automated driving functions
PEGASUS

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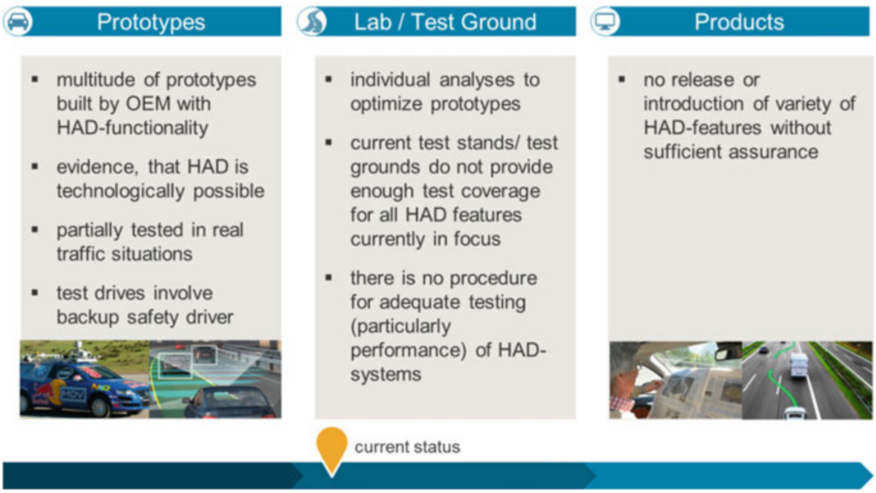


Prototypes

- multitude of prototypes built by OEM with HAD-functionality
- evidence, that HAD is technologically possible
- partially tested in real traffic situations
- test drives involve backup safety driver

Lab / Test Ground

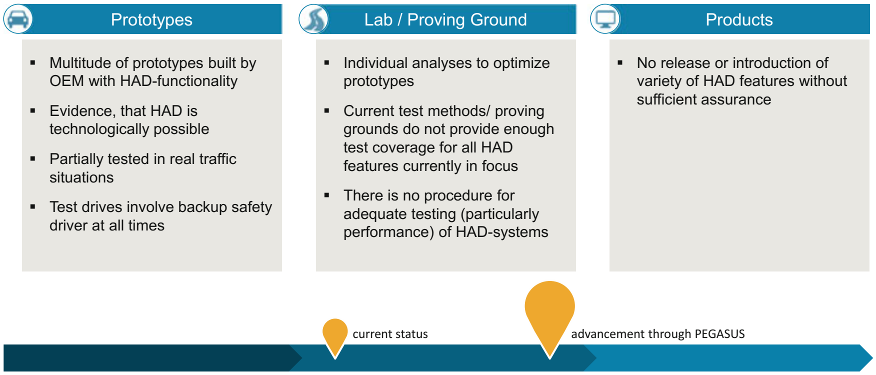
- individual analyses to optimize prototypes
- current test stands/ test grounds do not provide enough test coverage for all HAD features currently in focus
- there is no procedure for adequate testing (particularly performance) of HAD-systems

Products

- no release or introduction of variety of HAD-features without sufficient assurance

current status

Fig. 1 Current state of development of highly automated driving



Prototypes

- Multitude of prototypes built by OEM with HAD-functionality
- Evidence, that HAD is technologically possible
- Partially tested in real traffic situations
- Test drives involve backup safety driver at all times

Lab / Proving Ground

- Individual analyses to optimize prototypes
- Current test methods/ proving grounds do not provide enough test coverage for all HAD features currently in focus
- There is no procedure for adequate testing (particularly performance) of HAD-systems

Products

- No release or introduction of variety of HAD features without sufficient assurance

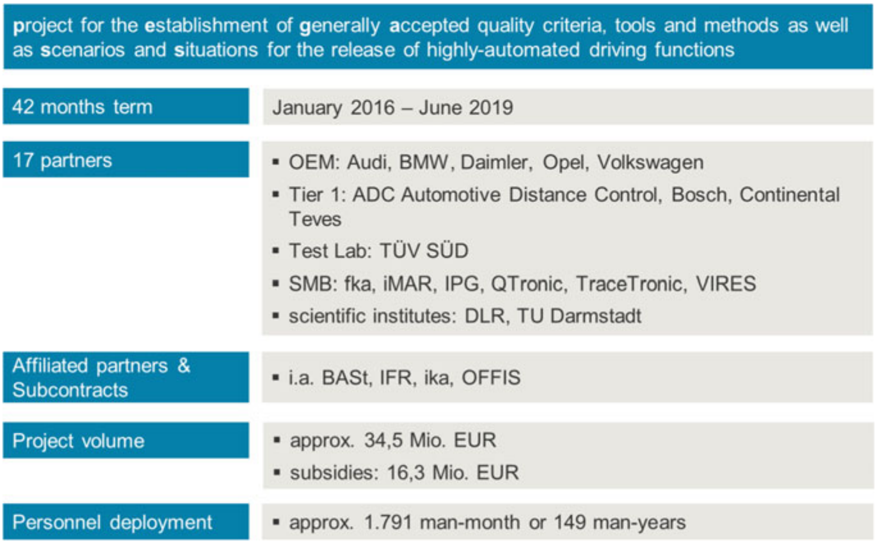
current status

advancement through PEGASUS

Fig. 2 Advancement through PEGASUS

1 Overview

17 partners from science and industry are working together on PEGASUS (see Fig. 3) to develop a complete toolchain to include criteria and measures for the evaluation of functions and for quality levels, with test catalogues, central methods, and processes for establishing the safety and make it possible to release highly automated driving functions (Level 3 according [1]). The toolchain will be



project for the establishment of generally accepted quality criteria, tools and methods as well as scenarios and situations for the release of highly-automated driving functions

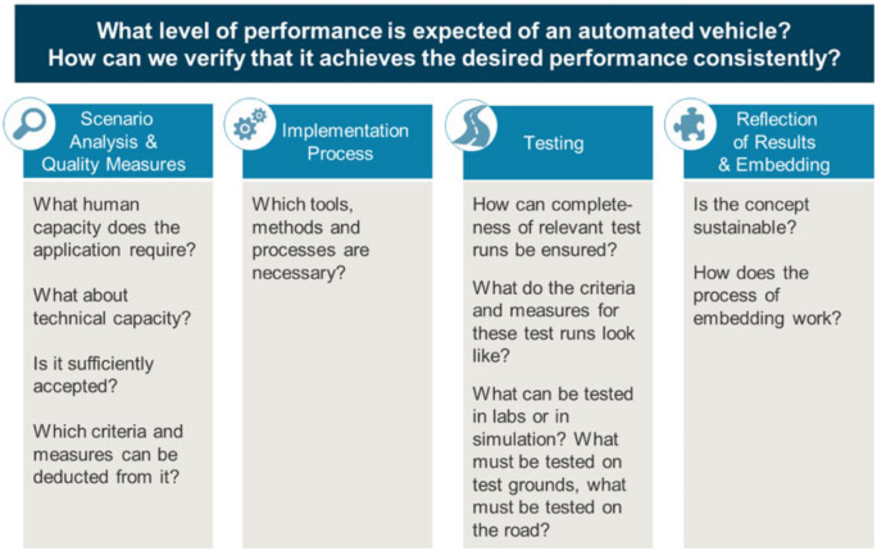
42 months term	January 2016 – June 2019
17 partners	▪ OEM: Audi, BMW, Daimler, Opel, Volkswagen ▪ Tier 1: ADC Automotive Distance Control, Bosch, Continental Teves ▪ Test Lab: TÜV SÜD ▪ SMB: fka, iMAR, IPG, QTronic, TraceTronic, VIRES ▪ scientific institutes: DLR, TU Darmstadt
Affiliated partners & Subcontracts	▪ i.a. BASt, IFR, ika, OFFIS
Project volume	▪ approx. 34,5 Mio. EUR ▪ subsidies: 16,3 Mio. EUR
Personnel deployment	▪ approx. 1.791 man-month or 149 man-years

Fig. 3 PEGASUS key-facts

developed as a prototype within the project and demonstrated in practice. The result will be a new state-of-the-art in technology and engineering across all manufacturers to ensure the safety of highly automated driving functions, preparing the way for subsequent release and approval. Implementation and validation will take place using the Highway Chauffeur as application example in order to develop the real-world functionality of the toolchain.

The project operates as four subprojects looking more closely at further, more detailed issues (see Fig. 4).

Subproject 1 “Scenario Analysis and Quality Measures” defines the Highway Chauffeur example application, human and machine performance, and the criteria and measures used for evaluation. Subproject 2 “Implementation Processes” analyses safety processes currently established within the automobile industry, transfers them into new or extended process methodologies for highly automated driving functions and works up the process specification for actual testing. Subproject 3 “Testing” develops methods and tools for carrying out tests in the laboratory, at the test site and in real traffic situations. The objective here is to cover as many tests as possible in simulation. Ensuring transferability and embedding of results into industrial processes is the task of Subproject 4 “Result Reflection and Embedding” by means of a proof of concept, amongst other tools.



What level of performance is expected of an automated vehicle?
How can we verify that it achieves the desired performance consistently?

Scenario Analysis & Quality Measures

What human capacity does the application require?

What about technical capacity?

Is it sufficiently accepted?

Which criteria and measures can be deducted from it?

Implementation Process

Which tools, methods and processes are necessary?

Testing

How can completeness of relevant test runs be ensured?

What do the criteria and measures for these test runs look like?

What can be tested in labs or in simulation? What must be tested on test grounds, what must be tested on the road?

Reflection of Results & Embedding

Is the concept sustainable?

How does the process of embedding work?

Fig. 4 Central issues of the PEGASUS project

2 Scenarios and Quality Measures for Automated Driving

In order to ensure efficient testing of (highly) automated systems, a large volume of diverse information is both useful and necessary. This information includes scenarios, suitable criteria and measures which permit an evaluation of the performance and quality of the system. Alongside the technical system, it is essential that we quantify human performance, particularly for use as a benchmark, in order to determine the requirements of a (highly) automated system and to ensure that quality of traffic at least remains the same.

The Highway Chauffeur example application is taken as a realistic basis for all investigations and developments for all subprojects. Based on Highway Chauffeur, tools will be created for determining critical traffic situations, human and machine capacities. The dataset is composed of existing sources of information such as accident databases (e.g. GIDAS [2], ZIDATU [3]), Naturalistic Driving Studies (NDS), Field Operational Tests (FOT) or driving simulator studies.

These data will be efficiently and automatically evaluated for critical situations using metrics developed within the project. Relevant conclusions regarding human performance in this situation can be derived in turn from the results and compared with machine performance. The result is a determination of the effectiveness of the automated driving function which can be equated with an accident avoidance potential. From the subsequent evaluation of the probability of occurrence and the ability of the automated system to control the critical situations identified, the required safety level can be determined and an accepted quality measure and system requirements can be specified (see Fig. 5).

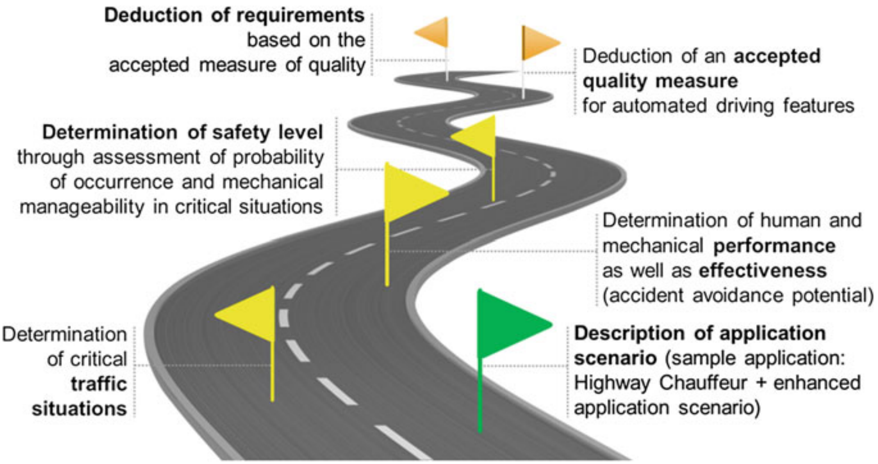


Fig. 5 Scenario analysis and quality measures

In order to make efficient use of the results acquired, they will be entered into the test specification database [4]. The other subprojects also have access to this database, make use of the data, further add to it and similarly save data here, e.g. the results of tests. All of the project results directly required for testing are thus available from a central source.

The fundamental metric perspective [5] in Fig. 6 details this approach, beginning with the start of the process at the bottom left, with the information sources from which the test scenarios will be developed. These will be structured and organised in test databases. The test performance and evaluation of the test results will be used to carry out a risk analysis. If the risk is below the comparison measure then the item can be released for series introduction.

3 Processes Required for Establishing Safety

In order to be able to evaluate requirements and quality measures as well as test results in a reproducible and comparable manner which is as consistent as possible, they must be fundamentally similar but sufficiently flexible so that they can be used by every company.

Accordingly, a process analysis and modification of the existing process in the automobile industry and a review of innovative concepts is required in order to establish unified testing for highly automated vehicles. To this end, PEGASUS will determine the required modification of existing and established metrics and processes (including functional safety) with a focus on the early phase of the product development model (V-model).

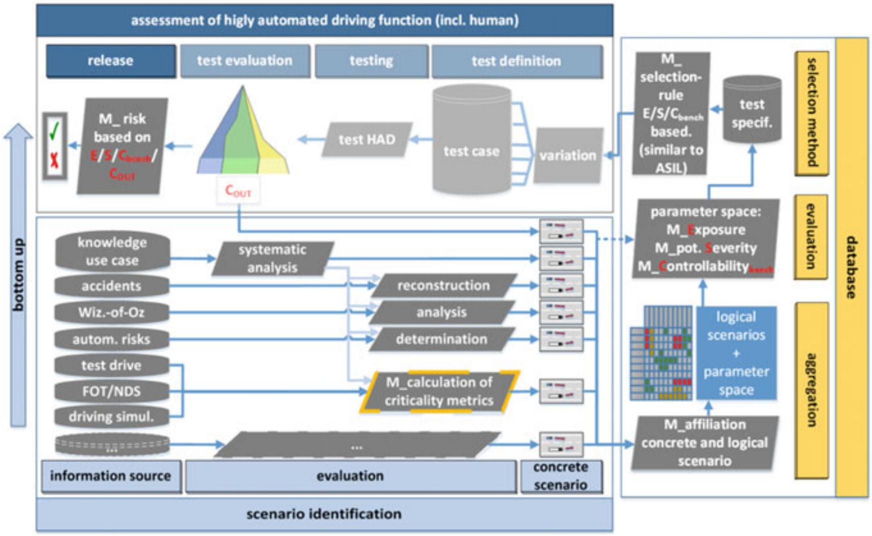


Fig. 6 PEGASUS metrics perspective

Building on this, and in close collaboration between the subprojects, the systematic scenario guidelines will be transferred into process steps taking into account system classifications and vehicle usage stages. Innovative concepts (e.g. breaking down the driving task) may additionally be transferred into processes which enable the derivation of further specific test cases for the driving task. For carrying out the actual tests, the requirements for simulation, test site and field tests and the test documentation in the form of guidelines and templates will be defined. The result will be a new and unified state-of-the-art in the field of development processes suitable for (highly) automated driving. Figure 7 shows the approach.

4 Actual Testing

In order to achieve a safe (highly) automated driving function, it must be guaranteed that this function can handle all anticipated driving situations and is thus “safe enough”. Whether the accompanying proof is achieved by means of field tests, test site testing or in the laboratory/simulator is left open. This kind of proof would require several hundred million (based on accidents resulting in injuries) up to almost 10 billion kilometres of driving (based on fatal accidents) for a highly automated driving function on motorways, see [6, 7]. If we carried out this driving exclusively on the road, this would be highly uneconomic and would not be compatible with the time constraints within the automobile development cycle. Accordingly, when it comes to actual testing, PEGASUS focuses on achieving the

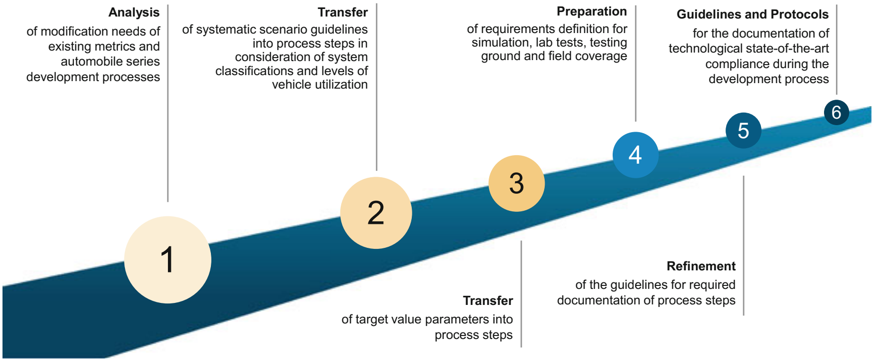


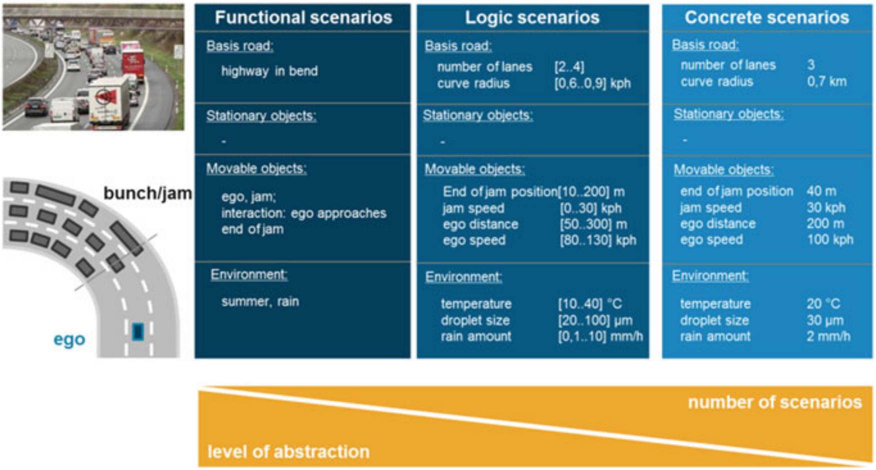
Fig. 7 Implementation process

greatest test coverage possible in the laboratory/in simulation (including software-in-the-loop (SIL), hardware-in-the-loop (HIL) or vehicle-in-the-loop (VIR) tests). It will nevertheless not be possible complete all tests purely in simulation; several models, for example in the field of sensor technology, are still showing too many weaknesses for this to be possible. Test results from simulation will need to be verified and validated on test grounds and in field tests.

Functional scenarios are the basis of all tests. At next logical scenarios with a specified parameter space will be developed from functional scenarios. A scenario instantiated with a concrete set of parameters out of this space deliver is called concrete scenario, ref. Fig. 8.

Which tests will be carried out in which environment will be defined in test preparation. Here, it will be ensured that the three test elements (simulation, test site, field tests) are closely meshed and complement one another. Thus test site tests verify simulation runs and field tests validate their results in turn. The basis for all test runs are the previously developed scenarios and quality levels and the processes and guidelines drawn up for the test. This information as well as the results of the tests will be centrally available in the test specification database. The quantity and quality of the test basis can be continuously increased by adding in new data and findings. The resulting toolchain will be put together in PEGASUS as an example in order to be able to demonstrate, test and evaluate practical fitness for purpose and usefulness. Figure 9 shows the schematic layout of the test procedure.

In order that testing conforms to standards, in some areas we will need to change the way we think—a paradigm shift is required [8–10]—from “safety by test”, the testing of a black box system, to “safety by design”, in which there is complete system knowledge of the complex vehicle system. From sensors to actuators, the condition of all components with regard to system integrity is observable here.



Functional scenarios	Logic scenarios	Concrete scenarios
Basis road: highway in bend	Basis road: number of lanes [2..4] curve radius [0,6..0,9] kph	Basis road: number of lanes 3 curve radius 0,7 km
Stationary objects: -	Stationary objects: -	Stationary objects: -
Movable objects: ego, jam; interaction: ego approaches end of jam	Movable objects: End of jam position [10..200] m jam speed [0..30] kph ego distance [50..300] m ego speed [80..130] kph	Movable objects: end of jam position 40 m jam speed 30 kph ego distance 200 m ego speed 100 kph
Environment: summer, rain	Environment: temperature [10..40] °C droplet size [20..100] µm rain amount [0,1..10] mm/h	Environment: temperature 20 °C droplet size 30 µm rain amount 2 mm/h

Fig. 8 Generation of scenarios: levels of abstraction

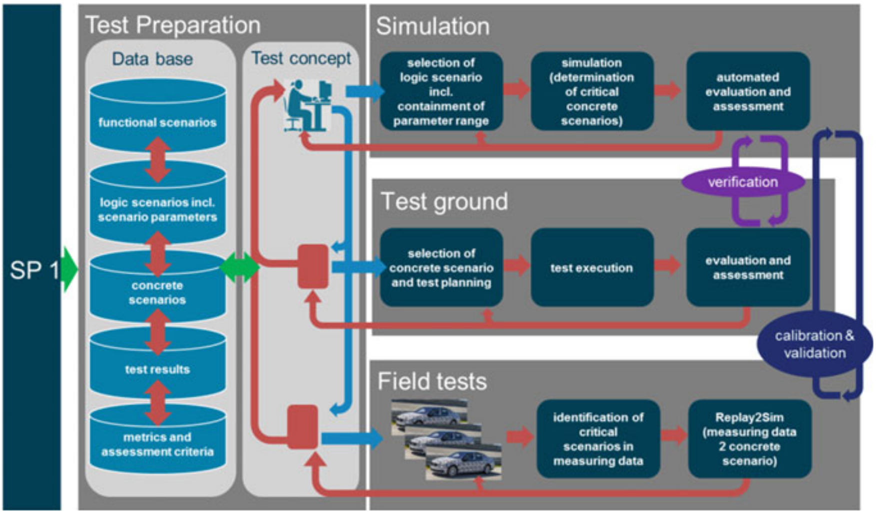


Fig. 9 Testing

Function limits are determined using simulator runs and the established scenarios. The entire function space is established with testing along these limits. This defined test space can be verified on the test site primarily along the expected function limits. The objective of the "safety by design" approach is to ensure sufficient completeness within the function limits by systematically creating scenarios and methods for test coverage.

4.1 Simulation

The ideal criteria for efficient testing using simulation and laboratory environments are that tests should be reproducible, cost-effective and as complete as possible. Thus, in the ideal case, the expected results and a wide range of situations and environmental conditions are looked at in simulation, integrating all vehicle components.

In order to achieve comparable and consistent testing PEGASUS relies on a unified description format for test cases and test results. The same applies for the models, interfaces, formats and tools of the individual elements of the toolchain, resulting in a modular toolbox for virtual testing.

4.2 Test Site Test

New and existing test site facilities/test equipment which can be freely combined with one another to achieve the most flexible testing possible—like a toolbox—are selected and used depending on the requirements and situations to be tested. PEGASUS offers a generic approach to this which enables practical demonstration of the required quality measure. Simulation results are verified based on the test preparation.

4.3 Field Verification

In the last validation step, field verification validates simulation and test site results. In the field, critical situations in particular are considered in which the requirements for the successful introduction of a (highly) automated system which are defined by traffic and behaviour must be verified in a real-world environment. This will also result in new traffic situations which can be fed into the test specification database in the “replay2simulation” process and are then available for further investigations (e.g. in simulation).

5 Proof of Concept/Transfer of Results

Continuous transfer of PEGASUS results into project partners’ product development is one of the essential objectives of this joint project. This requires that the results achieved in the form of methods, processes and tools must be sufficiently robust and efficient.

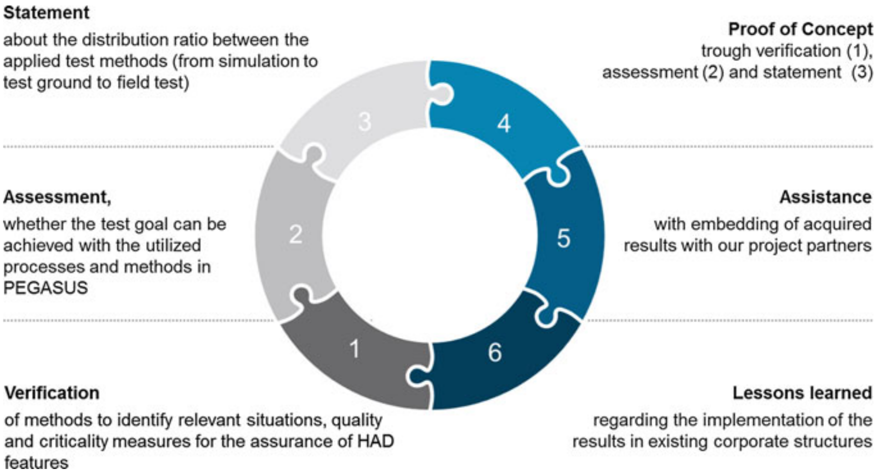


Fig. 10 Reflection of results & embedding

Therefore, throughout the entire project, a proof of concept (see Fig. 10) is employed as well as a continuous bullet-point style check of individual essential elements using a maturity management system. At the same time, the consistency of the requirements analysis is ensured right through to final testing. The traceability of this chain is evaluated using a traceability concept. This offers the opportunity of quickly and efficiently adapting test cases at individual points in a targeted way as requirements change, without the need to carry out a complete re-evaluation.

6 Conclusion and Outlook

17 partners from science and industry are working together in the PEGASUS project to define new criteria and standards for the release of highly automated driving functions.

Current test procedures, as used today in driver assistance systems, cannot simply be used without further work because they are too time- and cost-intensive for highly automated driver functions and, most importantly, are specific to each manufacturer. With PEGASUS, we will in future be able to be quickly and efficiently transfer the results of research and development projects as well as already existing vehicle prototypes to market-ready products. Until June 2019 the project partners are therefore developing generally accepted methods and tools for validating highly automated vehicle functions and demonstrating these using the Highway Chauffeur example system.

As part of the interim project presentation in November 2017, an international symposium was held on 9.11.2017 with the title “How Safe Is Safe Enough?”.

The results achieved so far were presented in the context of presentations by other international initiatives. More details can be found on the project webpage http://www.pegasusprojekt.de/en.

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Testing Connected and Automated Vehicles (CAVs): Accelerating Innovation, Integration, Deployment and Sharing Results

Mathieu Joerger, Cynthia Jones and Valerie Shuman

Abstract This session explored opportunities and best practices regarding connected and automated vehicles (CAV) testing throughout the industry. CAVs offer the promise of improved safety and performance, compared to the current human driver paradigm. Both closed course and open road testing are critical components of technology evaluation, improvement, integration and acceptance. Diversity of testing sites and attributes will multiply the scenarios tested and mitigate operating risk once the technology is implemented. The U.S. Department of Transportation (USDOT) has cited acceleration of learning and development expected from the mandatory Community of Practice within their Automated Vehicle Proving Ground Pilot Program. The first activity was a CAV Proving Grounds Showcase, followed by a panel and discussion on Roles and Partnerships in CAV testing, then a panel and workshop on Next Steps to Collaboration.

Keywords Connected vehicles, CV · Automated vehicles, AV
CAV · Testing · Innovation · Deployment · Safety · Proving ground
Partnerships · Policy · Collaboration

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1 Introduction

Automated Vehicle (AV) technology is being developed and piloted [1], as is Connected Vehicle (CV) technology [2], and together as Connected and Automated Vehicles (CAV) they offer the greatest potential to improve safety through reduced occurrence and severity of crashes. Pilot programs are emerging internationally, including many within US states. As CAV technology has developed there has been a need for CAV testing. Sites have been designed, funded and operated to test the CAV technology. Initial testing has taken place in closed courses, and has then moved to public roads. USDOT introduced an AV proving ground program to facilitate best practices [3]. In the same spirit, this session encouraged sharing information and best practices across all locations, methods and opportunities for testing CAV. As transportation experts develop and study the CAV technology, CAV challenges, and CAV impacts, there is a critical need for effective testing prior to deployment in order to mitigate risks (safety, acceptance, impact) in our complex transportation systems.

2 Exploring Opportunities and Best Practices

2.1 CAV Proving Grounds Showcase

Four USDOT-designated and two international proving grounds were presented during that part of the session, which was moderated by Andrea Gold from the Center for Transportation Research at the University of Texas, Austin.

These proving grounds all have multiple partners in industry, government, and academia. They all build upon existing facilities, local resources, and expertise. But, each proving ground focuses on testing specific aspects of CAV performance. One key take-away of this session is that further partnership and coordination is desired to further exploit the complementary capabilities of the different proving grounds. In the U.S. in particular where the government does not appear to be as tightly involved in CAV development as in other countries, the desire for tighter collaboration with DOT was repeatedly mentioned in presentations, although the fear of government interference is a concern to industry.

2.1.1 Texas Automated Vehicle Proving Ground Partnership, Bryan, Austin and San Antonio, Texas

This partnership regroups all CAV leaders in Texas who spontaneously gathered to obtain the DOT designation. The partnership encompasses multiple cities, and is steered by Texas A&M, UT Austin, and the Southwest Research Institute, which have expertise in robotics, UAVs, GPS, regulations, etc. A long list of local proving grounds is included in the partnership, offering a variety of testing environments such as high-speed tracks, bus routes, freight transportation, etc.

2.1.2 SunTrax and the Central Florida Automated Vehicle Partnership, Orlando, Florida

The SunTrax and Central Florida AV test facilities allow for testing of, and education on truck platooning in controlled and open test grounds. The partnership includes NASA, which is an asset for advanced technology development. The controlled track facility includes an urban simulation zone, high-speed tracks, and a system to test automatic tolling. In addition, driver-assisted truck platooning can be tested over 143 miles of road (the pilot project focuses on tandem trailers).

2.1.3 Iowa AV Proving Grounds, Iowa City, Iowa

The Iowa partnership includes the Iowa DOT, the University of Iowa and Iowa State University. It uses the University of Iowa's $80 M driving simulator to study how drivers would respond in fully automated vehicles. A virtual testing ground is developed, called 'Springfield'. Des Moines is at the confluence of interstate roads I35 and I80, and sees lots of freight transportation, which is a focus of the proving ground's investigations, together with improved safety, accessibility, and broader mobility for elderly people and people in need of assistance. One specificity of this proving ground is an effort to establish a high-definition database of the Iowa driving environment, and to make it publicly available.

2.1.4 GoMentum Station Contra Costa Transportation Authority, Concord, California

The 'GoMentum Station' has multiple test facilities, one of which is at Bishop Ranch, and another is a 5000-acre secure area available for CAV testing. This area is a former navy weapons station, and features paved roads, two 1400-feet tunnels, bridges, poles carrying electric cables, etc. all with worn-out road pavement and markings, which reflect realistic road conditions. Current partners include major car manufacturers, and automated car and truck driving companies. The next steps are to build upon the existing infrastructure to incorporate additional features of an urban environment.

2.1.5 UK Centre for Connected and Autonomous Vehicles, United Kingdom: London (Greenwich), Coventry, Milton Keynes, Bristol, Oxford, Cranfield Interurban Roads

This partnership was created in the heart of England and regroups existing facilities, companies and high-profile AV system developers. The partnership is expected to stimulate a self-sustaining ecosystem, where successes from the initial effort motivates and attracts new partners. The initiative started by taking feedback from car manufacturers and other stakeholders, who expressed:

- the need for real world testing grounds, as well as facilities under controlled environment to test new capabilities
- the desire to develop and strengthen existing capabilities, testbeds and simulations
- the interest for targeted government investment to help solidify these capabilities.

The success of this initiative relies on an open regulatory approach combined with government incentives for research and development.

2.1.6 K-City, South Korea

South Korea's proving ground was named K-city to mirror Michigan's M-city. It is advertised as the largest CAV testing facility, with 320,000 m^2 (88 acres) including motorways, urban areas, community/autonomous parking areas, rural roads, etc. [Since then, Alphabet's 'Waymo' self-driving car program has built a 91-acre testbed named Castle in Attwater, California]. The primary focus is on safety, and safety evaluations can be carried out over thousands of cases for many different scenarios.

Questions:

Questions following these six presentations revolved around the complementary aspects of the testing grounds. Is it efficient to have 10 USDOT designated testing grounds in the U.S., and many more around the world? The answer is that no one proving ground can encompass the wide variety of environmental conditions and scenarios that cars drive into. Weather, road infrastructure, and cultural driving behavior were identified as major sources of variability from one proving ground to the next. Partnerships between testbeds already exist, for example, between California and Singapore, to explore various aspects of driving.

In addition, the issue of test-data sharing was debated. Proving grounds do not own testing data. Data is typically owned by their customers (which include car and equipment manufacturers, and self-driving car companies). But, all proving ground owners and operators encourage their customers to share data; it is in the proving ground owner's interest to promote their facilities, and when universities are involved, to let testing results be published.

2.2 Roles and Partnerships Panel

Dr. Taylor Lochrane, USDOT FHWA Office of Operations Research and Development, moderated this panel and discussion which included three panel experts:

- Hajime Amano, President and CEO of ITS Japan
- Maxime Flament, Head of Connected & Automated Driving of ERTICO ITS Europe
- Brett Roubinek, President and CEO of Transportation Research Center, Inc.

An objective of this session is to explore the existing roles and partnerships in CAV testing. Diversity of testing sites and attributes will multiply the scenarios tested and mitigate operating risk once the technology is implemented. While the focus of the entire session is CAV testing, we acknowledge that it cannot be done by one person or entity. Therefore, understanding the variety of roles in testing, and building partnerships can improve the transportation system and CAV technologies.

2.2.1 ITS Japan

Hajime Amano, President and CEO of ITS Japan, presented an overview of their ongoing and future research. The Japanese government is investing in a testing platform to be shared between stakeholders, including JAMA (Japan Automobile Manufacturers Association), to boost the economy on CAV. One of five aspect of the project is the development of a “Dynamic map”, which will soon notify users on construction zones. In the longer-term future, if high-enough update rate can be achieved, updates on traffic and weather conditions may become available. Japanese roads have been equipped with vehicle to infrastructure (V2I) and vehicle to vehicle (V2V) communication infrastructure for many years. Research is ongoing to develop TSPS (traffic signal prediction system) and collision avoidance systems over 7000 intersections. Test sites will be available free of charge including in urban areas and on expressways. The National Police Agency issued rules to perform testing.

2.2.2 ERTICO ITS Europe

Maxime Flament, Head of Connected & Automated Driving of ERTICO ITS Europe, presented a summary of research work carried out in Europe (see http://connectedautomateddriving.eu).

European states have expressed interest in cooperation in the filed of CAV driving in the 2016 Declaration of Amsterdam. The presentation gave an overview of research efforts in Germany, France, UK, and Sweden.

Germany has developed multiple testbed in areas where major Original Equipment Manufacturers (OEMs) have their headquarters, for example, the A9 digital motorway testbed in Bavaria. The idea is to build basic infrastructure to facilitate CAV driving. This infrastructure includes message signs, roadside infrastructure/sensors, internet, HD maps, road markings, interactions with traffic management. Multiple experiments have been performed along A9 in Bavaria, and in 'VW-City', in Lower-Saxony.

In France, "France nouvelle" is a collaborative effort articulated around three topics:

- CAV testing,
- CAV ecosystem (legal, etc.) and
- CAV technology development.

Tens of thousands of kilometers of roads can be used for testing. Early successes were achieved in centers of expertise created to specifically address the above three topics. French-German cooperation is particularly strong in the Alsace region.

In the UK, major contributors to the UK partnership are innovateUS, UK autodrive, GATEway… and have been discussed in Sect. 2.1.5.

In Sweden, 'Drive Me' is a CAV leader in Europe, whose objective is to put Level 4 CAVs on the roads—the pilot program should have 100 families equipped with CAVs, and will start with Level 2 CAVs. Also, platooning of multi-brand trucks is being tested (including Volvo and Scania). 'AUTOPILOT' and 'L3 Pilot' are flagship programs for AVs. AUTOPILOT aims at showing how 'internet of things' standards can benefit AVs—there are five test sites in Europe and one in Korea. L3 Pilot targets L3–L4 CAVs using 100 vehicles and more than 1000 pilot programs.

One overall comment is that there are many heterogeneous efforts with a wide variety of goals, and that more coordination might soon be needed.

2.2.3 Transportation Research Center, Inc., Ohio, U.S.A.

Brett Roubinek, President and CEO of Transportation Research Center (TRC), Inc., presented work carried out in the U.S. The Ohio TRC draws many assets from the state of Ohio and from Ohio State University. The TRC testbed includes high-speed intersections, urban networks, vehicle dynamics areas, and a control center, which are all under construction under Phase I. In Phase II, an indoor weather condition facilities will be developed. In Phase III, a three mile loop to recreate highway settings will be constructed. The Ohio partnership involves multiple closely located partners, including the Columbus Smart City, City of Dublin, Marysville, and Ohio TRC. Fiber has been laid throughout the corridor to have this stretch of road connected. Expansion to a SMART Belt Coalition from Chicago to New Haven is under consideration.

Questions and Roundtable

We have noted that governments in different parts of the world were more or less involved in the automotive and CAV industry. For example, the U.S. government is not as tightly involved in CAV development as in Japan, Korea, and Europe. Several reasons were identified, including the fact that the government might not currently have the necessary knowledge and resources to intervene in a constructive manner. Coordination between stakeholders would help, but it will take time, it will likely be an iterative process, and many lessons are expected to be learned form first testbed attempts.

Questions were raised on how to promote CAV research efforts. CAV proving grounds are often developed to drive the local economy. How can these capabilities be better coordinated and harmonized, and how can strong, complementary partnerships be built? There is a need for consistent standards across states in the US, e.g., for platooning across multiple states.

2.3 Next Steps to Collaboration Panel

Valerie Shuman, Principal at SCG, LLC moderated the final segment of the program, which was a workshop in which over forty participants from around the globe contributed their ideas on what should be included in a Global Test Bed Collaboration Plan. This discussion was launched by a panel of experts, including:

- Carla Bailo, AVP Mobility Research and Business Development, The Ohio State University
- Ed Bradley, Program Manager, Product Regulatory Affairs, Safety, Toyota
- Sondra Rosenberg, Assistant Director, Planning, Nevada Department of Transportation.

Participants then gathered in roundtables to address the question:

> How can we leverage the combined power of all of our test beds to achieve the common goal of getting fully automated vehicles out there saving lives?

Roundtable Questions

Each of the tables was asked to rank their priorities in three areas:

- **Top five Research goals**. What do we want to learn? For example, guidelines for safe behavior on public roads, requirements for shared public infrastructure data to support full automation, etc.
- **Top five shared Test Results**. What tests should we be carrying out at multiple facilities to get a larger/more diverse shared data pool around specific issues? For example, interoperability testing, etc. This item was revised by the group to be "shared data and test results" to recognize the value of allowing multiple researchers across test beds access to data as well as to specific conclusions drawn from that data.

- **Top five Best Practice areas**. What areas will most benefit from sharing across test beds? For example, cyber-security best practices, consumer data management handling, etc.

Summary of Results

At the end of the session, each group reported their top priority in each area and there was a brief discussion to discover which priorities were shared among tables. A further review of the detailed results from each table revealed the following prioritized set of common topics:

- **Research Goals**

1. Human/machine interaction	• Interaction of human and autonomous "operators" • How do we communicate to human vehicle operators about system limitations? • Certification and safety assurance metrics for scoring or rating to communicate readiness and capabilities to users • Human factors (transfer within mode, HMI usability) • Assess impact from and to national regulations including the effect of out-of-the-loop driver activities • Human factors engineering
2. Performance	• Performance comparison to human drivers with diverse skill levels. Consider competency levels such as new drivers, CDL and other professionals, and elderly drivers • Common performance across sites and systems • Performance standards • Technology Readiness Level (TRL) equivalent for AVs, including problem specification • Competency test for vehicles
3. User acceptance	• What data needs to be gathered to gain public trust? What training is needed to make users knowledgeable and comfortable? How do we handle public exposure to technology? • How can proving grounds be used to educate and familiarize consumers with autonomous systems? • Public acceptance • User/society awareness of short term benefits and demonstrable added value
4. Specific technology and application areas	• Focus on core technology areas, including machine vision, connectivity and mapping • Identify which data public agencies need and map the data to public agency use cases. How is data informative and actionable for public operations and management? • Cybersecurity, connectivity and interoperability • Traffic congestion and safety • Safety and smooth network operation and user experience • Mobility for all ages and social groups

- **Shared Data and Test Results**

1. Common methodologies and standards	• Safety protocols, including stopping distances • Data collection procedures • Test procedures and methodologies—share with others doing similar testing • Common definitions, language and standards • Operational competencies—how testing was conducted • How do you gain white-box insights when you have black-box constraints? (Need to address the issue of white-box vs black-box testing) • Starting conditions; likelihood of someone altering/affecting the test • Develop some level of classification of what should be shared and how • Standardize processes, data and KPIs that allow comparison between tests, i.e., key variables • Global data sharing standards to address privacy and cybersecurity issues
2. Failure data	• Shared failures, including sensor discrepancies when sensors don't detect the same thing consistently • Near crash and crash dataERTICO ITS Europe—what led to these incidents? • AV system disengagement reports and requests for re-engagement • Test and crash fatalities
3. Weather and environment data	• Simulation of extreme weather conditions • Effects of differing site conditions • Geographic variations • Sensor accuracy/capability across environments

- **Best Practice Areas**

The groups provided a very diverse set of answers to this question. The two top answers are noted below, but quite a range of specific technical and institutional topics appear in the individual table discussion results below.

1. Standards	• What scenarios would every manufacturer have to navigate successfully • Advance standards and common approaches • Methods, measures and metrics • Standards development—do we have the data and information required to create standards? If not, how do we get it? • Neutral test beds for all OEMs • Standard testing guidance
2. Interoperability	• Communication interoperability

The full results of this session were documented in the *Global Test Bed Collaboration Plan Workshop Report,* which provides the input from each table, as well as a summary of the top issues contributed across tables. This content is offered as a starting place for the development of collaboration plans across test beds at individual, national and global levels.

It should be noted that in some cases there are already efforts emerging to establish shared research questions which will produce results to support standardization efforts (e.g., on data quality for automated vehicles). It is hoped that the results from this workshop will help to facilitate the development of many more such programs in furtherance of our shared goal: ***getting fully automated vehicles out there saving lives***.

3 Discussion and Future Direction

The thorough and diverse engagement during this session validates the AV testing concept as a necessary and timely one. This conversation is the beginning of the collaboration which will continue for years to come.

Some of the action items drawn from the session are:

- Continue conversations about effective AV testing, and share the Draft Global Test Bed Collaboration Plan. This is a critical, global concern that cannot be solved by U.S. government or any one party.
- Focus testing on safety to create our "Moonshot" with collaboration.
- Define roles to engage public, private and academic parties.
- Take advantage of opportunities to share through integrated data exchanges, especially with near crash and crash data.

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Challenges and Opportunities for the Intersection of Vulnerable Road Users (VRU) and Automated Vehicles (AVs)

**Justin M. Owens, Laura Sandt, Justin F. Morgan,
Sudharson Sundararajan, Michael Clamann, Dinesh Manocha,
Aaron Steinfeld, Tanvi Maheshwari and Jill F. Cooper**

Abstract This chapter presents a summary of AVS 2017 Breakout Session 13, *Challenges and Opportunities for the Intersection of Vulnerable Road Users (VRUs) and AVs*. This session built upon a brief session in AVS 2016 devoted to reducing conflict between VRUs and automated vehicles [1]. As last year's brief session resulted in significant engagement and discussion, this year's session was expanded to a full afternoon to broaden the scope of presentation topics and discussion. Nine speakers presented on a range of issues related to the intersection of VRUs and AVs, ranging from lessons from the real world, to themes in human factors, to simulation and urban planning considerations. The session was organized around two main panel themes, focused on *Vulnerable Road User Safety Needs and Concerns* and *Technology, Infrastructure and Policy Considerations.* Significant

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discussion during and following the formal presentations resulted in identification of a range of research needs, including in the domains of AV design and human factors research, communications, legal and ethical questions, and data requirements.

Keywords Automated vehicles · Vulnerable road users · Human factors
Intersections · Design · Portable devices · Perception · Behavior

1 Introduction

As the modern transportation paradigm shifts from human-driven vehicles to semi-automated and, eventually, fully autonomous vehicles, an area of critical importance is the interaction between vehicles and vulnerable road users (VRUs), particularly pedestrians and cyclists. The interaction between vehicle drivers and other road users, whether those sharing travel lanes or those attempting to cross the roadway, is currently governed by human perception, formal rules, social norms, and interpersonal interactions. As vehicles become more automated, however, this interpersonal interaction must transition to a human-machine interaction that will pose unique challenges to the wide variety of vulnerable road users.

In addition to the technological challenges facing the development of VRU engagement systems (e.g., pedestrian detection, behavior prediction, route planning, etc.), there are multiple human factors challenges that must be addressed before automated vehicle technology can ensure safe and efficient interactions between VRUs and AVs. These human factors challenges affect all aspects of the vehicle/VRU interaction, including determination of who or what is in control of the vehicle (particularly for partial or mid-level automation where the driver and

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automation share control responsibilities), bidirectional path and intention communication, and the planning of physical maneuvers to ensure safety and comfort for all parties involved.

The goal of this year's breakout session was to investigate a number of associated considerations from two major perspectives: the safety needs and concerns of VRUs and considerations for technology, infrastructure and policy. These two respective themes were explored during two presentation panels from speakers with a wide variety of expertise in the field, each of which was followed by discussion and audience engagement. This chapter presents an overview of the topics presented in each panel in Sect. 2, followed in Sect. 3 by highlights of discussion and recommendations for research needs and future discussion.

2 Presentation Panel Summaries

2.1 Presentation Summaries: Panel 1, Vulnerable Road User Safety Needs and Concerns

2.1.1 Welcome and Session Overview

Laura Sandt, University of North Carolina Highway Safety Research Center (UNC HSRC)

The first presentation panel was intended to provide a range of perspectives on specific needs and concerns to ensure safety for VRUs in the age of automation. Laura Sandt from the UNC Highway Safety Research Center opened the breakout session with an introductory high-level overview of the current state of AV/VRU interaction and several specific areas where improvement is greatly needed. The advent of AV technology presents the potential for improved road safety due to a reduction in human error and a potential improvement upon human perception, but it is important to consider the impact of vehicle automation on VRUs such as pedestrians and bicyclists. As all of us are pedestrians at one point or another, issues concerning VRUs must be addressed in order for the public to accept the advancement of AV technology. Several specific concerns discussed included the detection of VRUs by vehicle sensors, particularly during poor lighting conditions, and the lack of data and resources/studies concerning pedestrians/bicycles and AVs. This lack of resources results in an incomplete understanding and documentation of VRU safety considerations that may be improved by the conduct and dissemination of studies such as those presented in this session.

2.1.2 Reconstruction of Vehicle-Pedestrian Collisions: Powerful Data to Inform the Design of Automation and Active Safety Systems

Justin F. Morgan, Forensic Engineering Technologies

The first presentation in the *Safety Needs and Concerns* panel was given by Justin Morgan of Forensic Engineering Technologies, who provided current real-world context into the safety issues facing AVs and pedestrians. Vehicle-pedestrian collisions are events that frequently result in serious injury or death. The National Highway Traffic Safety Administration reported 5376 traffic-crash related pedestrian deaths in 2015, an increase of approximately 10% over the prior year [2]. While existing data speak to the number, frequency, and general location of vehicle-pedestrian collisions, more in-depth data regarding these interactions are not available. Understanding the context in which these collisions occur can help inform future AV operations to reduce the frequency and magnitude of vehicle-pedestrian crashes. Data from collision investigations and reconstructions provide such information. These data suggest environmental features and unexpected behaviors are common factors in vehicle-pedestrian collisions.

The built environment does not always support driver detection of pedestrians, and AVs are likely to encounter many of the same challenges. Common roadway factors identified in vehicle-pedestrian collisions include sight triangle deficiencies (i.e. limited lines of sight) and skewed intersections. These built-environment factors are difficult to revise, although technologies such as V2X communication, existing short-range sensing packages, and machine vision technologies may help mitigate the risk.

Unexpected behaviors are a major contributing factor in many vehicle-pedestrian collisions. Common examples include pedestrian crossings in reduced visibility conditions, crossings outside of marked or unmarked crosswalk locations, and turn path intrusions. Complicating this is that pedestrians typically overestimate their visibility to approaching motorists and fail to utilize conspicuity treatments [3, 4]. Thus, pedestrians' initial visibility to the driver can occur at a point where a collision is unavoidable. While aforementioned technologies such as wireless communication, on-board sensing, and machine vision may help reduce the frequency of such collisions in human-driver scenarios, AVs offer a further potential benefit by reducing the time necessary to respond to the initial presentation of the pedestrian. This effectively reduces the perception-reaction time (PRT) to the event, increasing the time and distance available for a response [5]. Even if AVs may not be able to avoid all pedestrian collisions, these technologies do offer the potential to at least mitigate the severity of the event. Therefore, a deeper understanding of the context of vehicle-pedestrian collisions may aid AVs in avoiding these common, and commonly-severe, collisions.

2.1.3 Key Human Factors Challenges and Opportunities Within AV/VRU Interactions

Justin M. Owens, Virginia Tech Transportation Institute (VTTI)

Transitioning from using real-world crash situations as tools to better understand conflicts to more theoretical considerations, Justin Owens from the Center for Vulnerable Road User Safety at VTTI presented a high-level overview of key human factors challenges and opportunities for the interaction among automated vehicles and vulnerable road users. The current interaction between drivers and VRUs is fairly well understood (albeit with significant imperfections, as illustrated by the previous talk) and relies to some degree on social interactions; in fact, many public safety campaigns focus on improving eye contact and gestural communication between pedestrians and drivers. As the vehicle fleet transitions to automation, vehicle-VRU interactions may shift from bidirectional human communication to human-machine interface (HMI) communication. Further, it is important to consider that roadways will host a mixed fleet of vehicle automation for the foreseeable future; roadways will not transition overnight to full automation. This mixed fleet comes with added challenges from interaction and interface-design perspectives.

Automated vehicle systems present a variety of potential benefits to VRU safety, including perceptual benefits such as reduced reaction time and behavioral advantages such as the preclusion of distracted, fatigued or angry drivers. These systems could potentially improve efficiency in pedestrian and traffic flow, and may provide opportunities for enhanced safety and mobility for pedestrians with disabilities.

At the same time, there is a need for increased human factors research with growing automation, in particular questions about the intersection between humans and AV systems. A recent publication by the Pedestrian-Bicycle Information Center (PBIC; [6]) presents a framework for discussion of technical and social issues associated with the interaction among AVs and VRUs. Key questions concerning these interactions include:

- How can AVs improve upon the ways that drivers and VRUs currently interact, such as via eye contact and gestures, and how could new interactions be supported by public outreach campaigns?
- How could AVs improve detection of pedestrians in the roadway, especially at night, in bad weather, or when there are occlusions?
- For midlevel AV systems (i.e., SAE levels 2 and 3), under what circumstances should the vehicle demand operator takeover, and will this vary in areas with high pedestrian traffic?
- What are the issues related to wireless V2X communications in detection of and communication with pedestrians and bicyclists?
- How should AV systems determine when and how to pass cyclists and pedestrians in the roadway?

- How can research guide development of AV algorithms to respond to cultural and geographical differences in pedestrian and bicycle behavior concerning issues such as local customs, right of way, jaywalking, passing bicycles, etc.?

In these domains and others, there is need for ongoing human factors work, both in the real world and using advanced simulation. A virtual reality driving simulator was presented that could enable the testing of AV-VRU communication systems without the risk that research on a real roadway entails.

2.1.4 Needs and Challenges of Pedestrians with Disabilities with Respect to Automated Vehicles

Sudharson Sundararajan, Booz Allen Hamilton

To conclude the first panel session, Sudharson Sundararajan from Booz Allen Hamilton presented on the specific needs and challenges that may be faced by pedestrians with disabilities when interacting with AVs. He discussed four primary types of disabilities that should be considered in the development of AVs, including vision, mobility, hearing, and cognitive disabilities. This discussion also included people with disabilities who are also veterans or older adults.

The need to address safety among people with disabilities is increasing worldwide each year. Additionally, medications and mental health issues affect roadway safety. Partnering broadly with stakeholders, including, for example, occupational therapists, is critical. Specific research needs discussed include:

- How AVs can be designed to accommodate people with disabilities who have unique pedestrian-related needs, including needing additional time to cross the street, have difficultly hearing automobile horns, may be less easily recognizable to machine vision systems, may behave differently at intersections, and similar needs.
- How AVs will be programmed to deal with issue of pedestrians with disabilities in the roadway, in particular the vehicles' ability to detect and correctly respond to pedestrians with functional differences from able-bodied pedestrians.

2.2 Panel 2—Technology, Infrastructure and Policy Considerations

2.2.1 Introduction

Michael Clamann, Duke University Humans and Autonomy Lab

The second panel, which focused on the technology, infrastructure, and policy considerations for the interactions between AVs and pedestrians, was moderated by Michael Clamann of the Duke University Humans and Autonomy Lab (HAL). Dr. Clamann opened with comments emphasizing the importance of multilevel engagement in the consideration of interactions between AVs and pedestrians. NHTSA has developed several guidance documents addressing AVs (e.g., [7]); however, there is minimal consideration of pedestrian safety needs within these. In addition to government agencies, pedestrian and bicycle researchers, practitioners and advocates should be present in national and state planning. Currently, there is a significant amount of state-level legislation pending around AVs, but the degree to which this legislation addresses VRUs varies considerably.

2.2.2 AutonoVi: A Simulation Framework for Autonomous Driving

Dinesh Manocha, University of North Carolina, Computer Sciences Department

Dinesh Manocha, a professor in the UNC Department of Computer Science, presented the first talk of the second panel, discussing a new tool for assisting in the development of autonomous vehicle interaction with crowds of pedestrians. The AutonoVi-Sim is a comprehensive simulation framework for evaluating and optimizing essential autonomous driving technologies. It includes algorithms for navigating complex traffic behavior including complex road environments, pedestrian/vehicle, and bicycle/vehicle interactions. The framework is modular to allow revision of algorithms, roadway features, and intelligent transportation systems (ITS), as well as new scenarios. Currently, project researchers are working to simulate challenges including varied road conditions, weather/lighting, realistic driving behaviors, a variety of social/cultural factors, and dynamic incidents including crashes.

Fundamental to the development of the simulator, researchers studied how drivers make vehicle control decisions regarding acceleration, deceleration, lane changes, and so on. They used these data to develop models and simulations of a wide variety of situations including situations with pedestrian and bicycles present. Next steps include using real-world data to test perceptual and behavioral learning. The overall goal of the AutonoVi framework is to develop a general-purpose autonomous driving simulator for research and industrial use. Further information about AutonoVi can be found in [8] and at http://gamma.cs.unc.edu/AutonoVi/.

2.2.3 Bystander Interaction with Autonomous Vehicles and Robots

Aaron Steinfeld, Carnegie Mellon University

Aaron Steinfeld, an associate research professor in the Robotics Institute at Carnegie Mellon University, presented and discussed several studies that explored issues of trust and behavior between users and robots, with the goal of better understanding how to improve acceptance and safe interactions between road users and AVs. In particular, it is important to determine what actions are appropriate in what contexts, how to properly set and avoid violating user expectations, how to avoid seeming “rude,” and how to engender trust (for example, that a vehicle will not collide with a pedestrian crossing a crosswalk). This last point is particularly interesting, as in some cases the knowledge that human drivers may *not* be trustworthy (e.g., drivers may go when it is “their turn”) may be important to stable traffic flow.

Example research included an investigation of the acceptability of a vehicle that can automatically park without the driver [9], which was intended to allow older adults and people with disabilities to get door-to-door more easily and safely, as well as a recent project that conducted survey research on the opinions of pedestrians about automated ride-share vehicles currently deployed in the Pittsburgh region. This latter research is expected to be available later in 2018.

2.2.4 Urban Form and Automated Flows

Tanvi Maheshwari, Future Cities Laboratory, Singapore

As the final presentation in the second panel session, Tanvi Maheshwari from the Future Cities Laboratory in Singapore addressed how an increasingly automated vehicle fleet will affect urban form and city design. The core question behind this discussion was the extent to which AV deployment can enhance the safety and overall experience of walking and bicycling, rather than limiting it.

Historically, innovations in transportation have altered urban form. Today the emergence of so-called ‘driverless cars’ or ‘autonomous vehicles’ is poised to transform transport flows in cities. Some scholars suggest that this amounts to an ‘urban revolution’ where automation will restructure the relationship of transport flows to urban forms.

Innovations in transportation technology have inspired grand urban visions. The most prominent among these was the automobile and highway based cities [10–12]. With hindsight of over 50 years, we can see how these visions translate in present day cities. This raises the question of how automated vehicles will impact the urban environment. Will they further the trends created by automobile-based cities, creating more segregated streets, and consequently urban forms? Or will they usher in a new era of shared streets and safety for VRUs?

In order to move in the latter direction, there is a need to develop indicators of urban design for vulnerable road users like pedestrians and cyclists that can be measured in an automated environment. Potential rider and environmental benefits of AVs such as improved safety and fewer emissions should be put into perspective with the risks and benefits to VRUs. Finally, the joy of traveling should also be considered, in addition to more quantifiable measures such as added capacity and speed.

In order to explore how to retrofit the current urban form to enhance the network for VRUs, the presenter is engaging in a series of workshops with inter-disciplinary set of experts in Singapore to imagine alternative urban scenarios for different types of AV deployments. These include:

(1) **Personal Ownership Model**

In this model car buyers can choose between human-driven or automated cars with various levels of automation. They can choose to drive or work while they are being driven. Car ownership becomes ever more attractive in this model.

(2) **Taxi and Ridesharing Model**

In this model we can effectively imagine the end of personal car ownership. All vehicles are shared, and probably run and managed by an enterprise. This model poses a danger of oligopoly by taxi operators. There could potentially be higher vehicle miles travelled and instability in service.

(3) **Government Regulated Fleet**

Automated vehicles are only allowed to operate as a government managed and/or operated fleet. With fully integrated public transit system and centralised planning, more control can be exerted over mode share distribution. This model can add to administrative burden and has political implications.

(4) **Restricted Use Model**

This model allows private use of AVs but only in restricted regulated areas. This may be due to lack of trust in technology or a means to control overall VKT. The use of AVs could be restricted to special highways, lanes, or closed areas like a college campus.

Each type of deployment system will have specific impacts on urban form. Conversely, for each type of existing urban form, specific deployment systems are more suitable. Through a world café workshop based format, urban design and policy interventions for each deployment system, as well as potential impact on other road users is discussed.

3 Suggested Action Items and Research Needs

Using the preceding presentations as a starting point, the breakout discussion throughout the afternoon identified needs for additional research in the following areas:

3.1 AV Design/Human Factors Research

1. Use current crash scenarios to predict conflict types and data needs for AV/VRU interactions.
2. Explore methods of AV detection of pedestrians and bicycles, and determine in what cases this may improve upon the current state of the art.

    a. In what ways can V2X communications assist in VRU detection?
    b. What are potential downsides to this technology from behavioral and technical standpoints?

3. Research should be conducted into the technical, human factors, and cultural issues surrounding communication of intent among AVs and VRUs.
    a. Given the variety of traffic cultures, how is right of way determined and communicated in different situations?
4. Explore designs that can respond to cultural and geographical differences in pedestrian and bicycle behavior concerning right of way and social customs.
5. Research should be conducted to optimize the passing behavior (both decision and distance) of AVs around VRUs, particularly bicyclists.
6. Explore the use of simulators to test interactions between AVs and VRUs. Include a range of VRUs including older adults, child pedestrians, people with different disabilities, etc. Explore issue of AVs passing bicycles.

3.2 Communications

1. Develop and test messages needed to educate the public about the operation, interactions, and benefits of AV technology.

3.3 Legal/Ethical Questions

1. When can AVs break the law (e.g., to cross a double yellow line or speeding to pass cyclists)?
2. Who is liable in case of crash?
3. Where is the legal responsibility in crashes involving non-AV vehicles, AV and VRUs?

3.4 Data

1. Explore driver assistance technologies that currently work well.
2. Build a database consisting of AVs and VRUs interactions, crashes, and lessons learned.
3. Explore standardization of data.

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Part V
Transportation Infrastructure and Planning

Autonomous Vehicles and the Built Environment: Exploring the Impacts on Different Urban Contexts

William Riggs, Nico Larco, Gerry Tierney, Melissa Ruhl, Josh Karlin-Resnick and Caroline Rodier

Abstract Autonomous Vehicles (AVs) offer a new entryway into society-wide conversations regarding transportation, functions of cities, the use of streets and, ultimately, urban sustainability. AVs are likely to disrupt urban spaces from city centers to the suburbs and rural edges of cities. This chapter focuses on these places. It tests potential changes to the built environment in two different urban contexts; a street-car suburban location (circa 1920s–30s) and a post-war suburban location. The outcomes from these tests are used to offer insight into how autonomous technology may have different impacts across space. The outcomes also reveal AVs may impact modal decisions differently based on location, and how planners and policy makers might frame built environment solutions to promote sustainable and livable urbanism.

Keywords Autonomous vehicles · Built environment · Cities · Urban planning

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1 Introduction

With the rise of autonomous vehicles (AVs), there are clear opportunities to reshape cities. AV technology will likely increase productivity and reduce collisions. At the same time it will connect individuals to jobs and change the way cities organize space and optimize trips [1, 2]. AVs offer a new entryway into society-wide conversation about transportation, functions of cities, use of streets and how all of these issues impact equity, environment, social cohesion and happiness, local economies, and more [3–5]. They are likely to disrupt things from city centers to suburbs to at least the urban/rural edges [1].

That said, cities can and do control what happens on streets and land, and therefore still have an active role to play in determining how people move around their jurisdictions [6]. AVs may add to the mix of transportation options, replacing some current forms of transportation, and could bring about changes to land use systems in a wide variety of ways [2]. Ultimately, how cities regulate the use of streets will be key since competition for limited space will only increase.

This chapter focuses on those potential changes to the built environment in 2 different urban contexts: urban, street-car suburban (circa 1920s–30s), and post-war suburban. These two cases offer a potential window into how AV technology may have varying physical design and behavioural implications in locations that have different built environment attributes.

First, we provide a brief literature review focusing on the built environment and behavioural dimensions of AVs. We follow this with an explanation of our process and methods. This, then, sets up our findings. We conclude with some illustrations of how our findings might be applied in real locations. These cases provide both a design and policy framework for further dialogue and research.

2 Background

Self-driving cars offer clear opportunities to shape advances in transportation and harness them to reshape cities and improve the socio-economic health of cities [7]. There are opportunities to reduce collisions, improve access to healthcare and to connect individuals to jobs and change the way cities organize space and optimize trips [1, 8]. Yet, much of research to-date has primarily focused on predicting and responding to the technological aspects and deployment [9–11]. Much less work focuses on the urban design implications or identifying and addressing potential secondary impacts. These secondary implications may end up being the largest obstacle to the successful rollout of AVs—particularly with regard to the disruption, and direct backlash, the rollout will create. They also highlight the importance of scenario and uncertainty planning [3].

Research has argued that the public health benefits of autonomous vehicle policies are without parallel, and will help cities realize the United Nations

Sustainable Development Goals to ensure healthy lives and create sustainable cities, and provide a basis for public health participation in transportation policy reforms [12]. Research has also suggested that autonomous and networked vehicles will lead to reduced transport costs, reduced need for parking, but potentially add to congestion [13]. This work on autonomy is compounded by the revolution in networked and data driven personal travel via companies like Uber and Lyft, which some say have the potential to reduce automobile ownership in urban areas with the potential to facilitate first and last mile connections [14, 15, 14] and to allow for convenient point-to-point mobility, and compliment transit [16]. While this technology potential may hold parallels to how travelers will behave in an autonomous future, other work has suggested that this smart and connected form of mobility may reduce public transit ridership and increase vehicle miles travel (VMT) [17], in addition to creating complicated pick up and drop off issues [18].

Some research suggests that shared autonomous systems can reduce parking land consumption by 4.5%, at a 5% market penetration level [19] and that many users may prefer sharing-based service model over private ownership [20]. This would lead to decrease VMT. These papers suggest, that individuals who currently own a car and have not used ride-sharing are likely to adopt AVs with an ownership or combined-ownership model. Yet most of these papers rely on optimistic assumptions, and there is contradictory research suggesting broad increases in vehicle miles traveled [21].

In this light it is important to consider the built environment and secondary effects of autonomy, including the impacts of AVs on things like: street design [22]; livability [23] and municipal budgets [24]. Harrington and Schenck [25] outline five initiatives that policy makers need to consider when assessing the impacts of AVs on the environment which include (1) smart growth, (2) mobile source planning for ozone nonattainment, (3) urban brownfield policies, (4) renewable energy policies, and (5) environmental justice. This chapter focuses on a number of these domains, as well as actions that can be taken to "future-proof" cities for the autonomous revolution.

3 Methodology

As stated in the introduction, this article documents a workshop conducted in July 2017 at the Autonomous Vehicle Symposium (AVS 2017). It outlines our process, frames the dialogue and provides illustrations of the outcomes. To evaluate various scenarios, we used a community-based "charrette" method, engaging participants. Community-oriented design and participatory action research is a common method in the field of city planning, but also has been used in public health and transport [26, 27]. TO engage in such research, experts facilitate and participate in a series of dialogues with the community to find normative solutions.

As a qualitative method the solutions become valid when there is a level of similarities (or saturation) in the ideas dialogued [28]. As a rule, this level of saturation requires a range of 16–30 individual participants (although it can be achieved with as few as 9–11 participants) [29]. Further, such planning methods are valid because they can help provide a better understanding of irrational human behaviour “that moves beyond agency and structure” [30]. Put simply, design of the built environment is comprised of both quantitative and qualitative factors. This humanistic method attempts to rectify those factors—both the quantifiable (for example street widths and number of collision) and the unquantifiable (the pedestrian experience and pleasant a place is for travel).

The charrette process at the AVS 2017 began with presentations to educate the group, followed by a description of prototypical sites—street-car suburban and post. The first site was a more urban site—a pre-war, 1920s urban (streetcar suburb) with a commercial neighborhood and surrounding residential area. The second site was a more suburban location—a post-war, 1970s, auto-centric suburb with a big-box strip mall surrounding residential development. The goal was to consider the pressures the sites might face as a result of emerging technologies and how they might change and adapt over time.

Participants (approximately 40 urban design, development, planning and transportation experts broken into groups with multiple groups assessing the same sites) were given a brief description of each site and encouraged to consider both optimistic and pessimistic scenarios. They were asked to assess how the site they were reviewing might develop, change, or adapt over time in an autonomous future. The collective outcomes and feedback were then synthesized and discussed, offering potential takeaways and observations.

4 Methodology

Charrette participants outlined two distinct potential outcomes based on the related urban typology. These explored how autonomy might shape cities. The charrette process began with presentations addressing secondary impacts and issues of AVs, such as the effects on land use, district design, sprawl, mode choice, parking, and street design.

Following these presentations, workshop participants evaluated the two prototypical sites in groups of 4–6 individuals. The sites (again, street-car suburban and post-war suburban) were based upon two existing sites in Portland, Oregon, as shown in Fig. 1, however, the sites were meant to represent typical conditions around the United States. Participants were asked to assume at least a 50% proliferation of level-5 (fully autonomous) vehicles, and were provided with the prompts listed in Table 1.

Fig. 1 Prototypical urban and suburban locations

4.1 Pre-war 1920s Urban

The first site was a more urban site—a pre-war, 1920s urban (streetcar suburb) with a commercial neighborhood and surrounding residential area. Workshop participants identified that the primary existing features of this example included:

- A walkable development grid, well served by bus and light rail, and including a major cut-through arterial.
- A one-to-three story commercial core surrounded by single family homes, as well as neighborhood serving commercial and a few regional retail draws.
- A substantial amount of surface parking and a few parking structures also present infill development opportunities.

The groups felt these kind of neighborhoods would adapt well to the new technology given that they already had a multimodal transportation footprint [31] and had a density that would support shared used of vehicles. There was consensus on the following potential changes and adaptations for the pre-war streetcar suburb:

- Consistent with research suggesting that there might be potential parking reductions of up to 90% in a shared AV environment (shared being a key assumption) there will be *opportunities for infill development* [32].
- Some of the freed-up parking lots and auto-serving uses could be *repurposed to neighborhood parks.*
- Despite trends in retail reduction, the “artisanal” and service-oriented nature of retail in these locations make them more resilient to trends in e-commerce and their agglomeration is *well suited to shared AVs and enhanced transit* [33].
- *Road diets will enhance walkability and bike use* [22, 34].

Table 1 Participant prompts

Land use
Land use—What land uses do you think will change in this area?
Retail (which types will stay, which will change?)?
Auto-oriented uses?
Commercial development?
Residential development?
Warehousing?
Land valuation—How will land values change?
What effect do you think this will have on development?
Are there any ‘centers’ you think might develop in this area
Transit—How might transit be affected by the scenario changes
What effect might this have on development patterns?
What effect will this have on land values?
Space and physical design
Parking—What do you think will happen to parking?
How much of it will we need?
What changes might happen to on-street versus off-street parking?
How might it be redeveloped
Street network—What will happen to the street network—will there be any changes?
Street design—What will happen to principal streets/street sections?
Number of lanes/Lane widths
Drop-off zones
Bicycle/Ped infrastructure
Density/proximity versus sprawl dispersion
Density of development—What will happen to overall densities of development
Retail? Commercial? Residential?
Will people want to be closer together or further apart (or both)?
Residential preferencing
Do you anticipate a population shift here?
Will AVs make living on/near this site more or less desirable?
Activity/vitality
How might pedestrian street life/buzz/activity change in this scenario?
How will the rise of e-commerce impact street buzz?

4.2 Post-war Big-Box Suburb

The second site was a more suburban location—a post-war, 1970s, auto-centric suburb with a big-box strip mall surrounding residential development. Workshop participants felt existing features of the post-war suburban landscape included:

Fig. 2 Participants felt there would be e opportunities to densify and connect more suburban areas

- A development centered around a big-box strip mall, located along major arterial, with large parking areas and a mix of local and regional commercial and retail.
- A commercial area surrounded by single-family residential developments with access on via one road (a typical loop and lollipop suburban form).
- An auto-oriented community with poor to non-existent pedestrian or cycling amenities, and minimal transit service.

As shown in Fig. 2, workshop participants felt that the impacts of AVs on these locations would likely be more significant than other locations—that they would be more challenged and more adaptation would likely be required. They felt that what made the future unclear was the vast potential for changes in the retail sector due to e-commerce. They agreed on the following potential changes and/or adaptations for this suburban typology:

- AV-induced reductions in demand for parking, combined with e-commerce, might provide *opportunities for infill development* at the current big-box strip mall.
- Assuming this infill, increased density might *create opportunities for enhanced transit.*
- Vacated and reduced footprint big-box retail *will require catalyst tenants or activities to prevent blight* (e.g., entertainment or cultural focus).

- Consistent with recent reports on the impacts of AVs on municipal budgets [24] *on-line retail will reduce municipal sales tax revenues* generated. This will likely have the most impact on big-box retail outlets, and cities need to find alternative tax sources.
- Major opportunities exist for road diets to *enhance walkability and bike use*.
- Consistent with recent work that has already shown racial and gender discrimination by transportation network companies [35] there are potential equity implications if these places (and even more so in rural locations) go underserved by AVs and shared vehicles.

5 Outcomes

What are the key takeaways from these exercises? Clearly autonomous vehicles have the propensity to reshape our urban landscape in many of the same ways that automobiles shaped cities during the 20th Century. There will be pressure to expand outside of the traditional urban core as mobility becomes cheaper and time in vehicles less of a productivity burden. Traditional auto-serving urban land uses may need regeneration—most notably parking. While these may impact many urban contexts, the impacts on suburban retail may be more acute.

Ultimately, a broader focus on community visioning and public engagement ultimately is needed. Communities need to organize and dictate the types of environments they want to see in the future. While we assume that the deployment of these technologies may improve quality of life, without appropriate advanced planning and policy, we may face continued problems with urban livability, equity, and health. Planners, administrators, and elected officials cannot simply think about how to accommodate these technologies as they develop—they must help facilitate the public vision through policy and the technology conform to that policy.

In light of that, it is worth illustrating a few locations cities that are taking policy action to better understand how planners, policy-makers and design can work with the automotive and technology industries to build the new mobility cities of tomorrow.

5.1 San Francisco and the Bay Area: Policies and Design

San Francisco has taken a high-level, values-based approach to prepare for AVs. For example, four city agencies have collaborated in scenario-planning-based visioning effort called ConnectSF to guide the city in a high-stakes, highly uncertain planning context. The process, which involved partnering with public, private, and non-profit community stakeholders to envision multiple possible futures for transportation and land use in San Francisco, identified key drivers of change, described potential future scenarios, and explored implications for those who live, work, and play in San Francisco. The resulting vision plan will ultimately guide projects and plans throughout the city [36].

Similarly, two San Francisco transportation agencies have developed Guiding Principles for Mobility Services and Technologies [37] that they will use as an approach "for the consistent application of policies and programs" and to "identify ways to meet city goals, and shape future areas of studies, policies and programs." While these principles are relatively general, covering topics such as sustainability and accountability, it is an important first step in shaping cities for people in an era of AVs.

Meanwhile, the wider San Francisco Bay Area's planning and financing organization, the Metropolitan Transportation Commission (MTC), is developing a more actions-based approach by defining a set of strategies to inform regional planning processes. The resulting 'Autonomous Vehicles Strategy Report' will draw from a set of policy guidelines for cities generally including:

- NACTO Blueprint for Autonomous Urbanism with strategies such as requiring speed limits for AVs in urban areas and programming an informational transparency campaign [38, 39]
- NCHRP Research Report 845 Strategies to Advance Automated and Connected Vehicles with strategies such as subsidizing autonomous mobility that is shared or updating contracting mechanisms for public-private partnerships [40]
- Urbanism Next Rethinking the Street in an Era of Driverless Cars with strategies such as road pricing and creating policies against roadway expansion [22].

The report will ultimately provide strategies for the Bay Area-wide land use and transportation planning effort called 'Plan Bay Area.'

5.2 Chicago and Beyond: Use Fees that Target Behaviour

Likewise, there are efforts away to begin experimenting with ride-hailing services like Uber and Lyft as a precursor to AVs. Some cities have put in place per-ride fees, and if autonomous vehicles are generally adopted as part of ride-hail fleets, the approach could be an instructive model.

Chicago, for example, established a flat 52-cent fee on each ride hail trip in 2015. In addition, the city recently approved a 15-cent hike for 2018 and an additional five-cent hike for 2019. Policy makers have attributed reductions in transit ridership and parking demand to the services, and they plan to use revenues to support transit service improvements. Much of the $16 million the fee increase is projected to rise in 2018 and $21 million in 2019 will be earmarked for the Chicago Transit Authority (CTA).

There is a growing body of evidence that ride hail services have reduced transit ridership. Studies out of New York City and California indicate some users of the services might otherwise use transit more frequently. The use of such services may also be having broader effects on the transportation system, increasing vehicle miles traveled and, in turn, both congestion and wear-and-tear on roads. Cities will need to find a way to recoup the costs of this behaviour on infrastructure and patch budget holes as existing fund sources like parking revenues decline.

These may be leading-edge indicators of what could happen if autonomous vehicles are adopted as shared mobility resources, along the lines of the ride-hail business model (or even deployed by ride-hail companies like Lyft and Uber). Ride hail services have increased the availability of door-to-door rides and lowered the barriers to requesting such services. Autonomous vehicles could make such services more widely available and reduce per-ride costs even more dramatically, which would be expected to spur further increases in demand.

Ideally, a fee system would scale to address the range of challenges ride-hail services have already raised. Charging a per-mile fee, rather than a per-ride fee, and setting it to reflect vehicle travel distances holistically (including time when vehicles are circling or returning from a revenue trip, when passengers are not in the car) would both recoup revenue and send a price signal to drivers and passengers that would reflect the externalities of certain types of travel behaviour. Sao Paulo briefly explored per-mile fees in 2014. Fees could also scale to the number of passengers in a vehicle, with lower per-passenger fees for higher occupancy vehicles.

6 Conclusions

As was shown through the AVS 2017 workshop exercise, there are many potential benefits of autonomous technology, but we must begin planning and implementing policy to achieve those benefits. Cities must recognize costs and the downstream impacts of AV development and deployment—things that have the potential to fundamentally change so many aspects of how we live, where we shop, what we do, and how we move about our environment. These costs, and potential perils must be addressed to the benefit of the public—promoting livable, sustainable and equitable communities, not just transportation efficiency.

In that light it is the job of planners, engineers and policy makers to engage stakeholders in a meaningful manner—something that our charrette provides a template for doing. Citizens have a role in defining the future of their cities, and there should be wide dialogue on the pertinent built environment, behavioural and social concerns that our moves toward autonomy bring up. These concerns are more tacit than the fearmongering of the rise of a "robopocalypse" [41, 42] or the technophobic theory of Jacques Ellul [43]. They relate to the future economic, social and environmental sustainability of cities.

We, the authors, challenge local policy makers and planners to enter to a dialogue with original equipment manufacturers—to collaborate and interface with technologists. Policy needs to evolve as more quickly, and the built environment must keep up with the rapid pace of technological change. So, in the words of Handy [44], "let's get on with it," and start assertively shaping the *promise* of the autonomous future.

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Enhancing the Validity of Traffic Flow Models with Emerging Data

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Abstract Modeling the impact of connected and automated vehicles (CAVs) on the environmental sustainability, mobility and safety of roadway traffic at the local link level or the regional network level requires a significant amount of currently non-available data. Multiple CAV test-beds and data collection efforts utilizing the latest sensing and communication technologies have been however publicized over the past few years. Such efforts have been led by the industry and public agencies in the US and abroad. Accordingly, (1) researchers and practitioners should be aware of the type and quantity of data needed to calibrate and validate traffic models while taking into account the impact of CAV technological specifications, the driver behavioral characteristics and the surrounding driving environments. (2) Moreover, the gap between such emerging data needs and the data made available to researchers or practitioners should be identified. This chapter summarizes the presentations of speakers that are investigating such gap during the Automated Vehicles Symposium 2017 (AVS17) held in San Francisco, California on July 11–13, 2017. These speakers participated in the break-out session titled "Enhancing the Validity of Traffic

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Flow Models with Emerging Data". The corresponding discussion and recommendations are presented in terms of the lessons learned and the future research direction to be adopted. This session was organized by the AHB45(3) Subcommittee on Traffic Flow Modeling for Connected and Automated Vehicles.

Keywords Traffic flow modeling · CAV/AV · Deployment · CACC Data · Test-beds · DSRCs · Platooning · Calibration/Validation

1 Introduction

Experts from the cyber-physical, communications, vehicle and traffic flow communities are needed to better understand the fundamental characteristics of traffic flow with varying levels of automation and to identify the research needs for developing models to assess real-world mobility and environmental sustainability implications of connected automated vehicles (CAVs). In particular, (1) there is a need for a discussion of innovative traffic flow modeling techniques and simulation tools to quantify the mobility and environment impacts of CAVs and their implications on highway capacity and freeway operations and designs [1]. (2) Special attention should be given to insights into behavioral differences in terms of lane-changing (lane choice, lane change execution) and car-following (following gap, reaction time, acceleration distribution) maneuvers and validation of existing and new CAV traffic flow models according to empirical data from CAV field tests.

Towards studying the CAV modeling efforts mentioned earlier and the gap between the available and the required data to support such efforts, the Transportation Research Board (TRB) AHB45(3) subcommittee on "Traffic Flow Modeling for Connected and Automated Vehicles" organized a breakout session at the Automated Vehicles Symposium 2017 (AVS17) held in San Francisco, California, on July 11–13, 2017. The breakout session titled "Enhancing the

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Validity of Traffic Flow Models with Emerging Data" brought together four scholars from academia and the industry. These scholars presented their latest work in CAV modeling and data collection efforts. Following the presentations, a panel consisting of the four invited speakers had extensive discussions with the audience. This chapter summarizes the four presentations made while identifying the data needs to model the impact of CAVs on the environmental sustainability, mobility and safety of roadway traffic at the local link level or the regional network levels.

The remaining sections of this chapter are organized as follows: Sect. 2 presents the summary of the four presentations and Sect. 3 introduces the key results from the panel discussion.

2 Data Needs and Modeling Methods

This section presents a summary of the four invited talks, which addressed the data collection efforts made and the challenges in utilizing such data to calibrate and validate traffic flow models that take into consideration the impact of CAVs on traffic mobility, safety and sustainability.

CAVs will have significant traffic impacts at different levels, from individual vehicle interactions, to system-wide aggregate effects. Impacts may take the form of strategic (trip, mode, and route choice), maneuvering (lane, speed, and gap choice), and control (steering, acceleration). The corresponding effects on traffic will depend on CAV technological specifications and the corresponding parameter choices. In view of such impacts, several major open questions remain to be answered by traffic flow researchers: (1) are existing traffic flow models good enough in describing driving behavior, and how it reacts to CAV related technological advances? (2) Do they differentiate the decision-making process for different levels of automation? (3) Do we, as practitioners and users, understand the corresponding differences? Answering such questions requires additional data collection efforts for traffic flow modeling, calibration and validation.

2.1 Using AV Pilots to Influence Public Opinions[1]

Governments (such as Australia) are providing opportunities for AV pilot programs. The main interest of such governments is related to influencing public opinions associated with CAVs while collecting data on the CAV user perception. For example, a demonstration in Adelaide on public roads reached 15 million viewers through Australia and New Zealand Driverless Vehicle Initiative (ADVI) media coverage. A public perception survey found widespread CAV acceptance, although

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[1] By Rita Excell, Australia and New Zealand Driverless Vehicle Initiative.

the related levels of comfort and concern varied based on the technology presented and the suggested use [2]. For example, 46% of the survey respondents believe AVs will be safer, but 83% would like to drive manually from time to time. The comfort varied for different driving tasks, such as lane changing and route choice. 38% of the respondents were willing to pay more for automation. Given the answers received, it is crucial to have CAV testbeds that involve public roads. Cities are willing to open their roads for testing, but additional investment or further focus on specific spatial boundaries for testing could generate more usable data. At this stage, in Australia, data collection is qualitative in nature and less organized. The quantitative usable data mainly includes how CAVs respond to existing infrastructure, markings, and signage with a lesser amount of data on the interaction between CAVs and roadway users (i.e. drivers, cyclists, pedestrians and transit users).

2.2 Connected and Automated Vehicular Flows: Modeling Framework and Data Availability[2]

Advanced CAV technologies enable us to modify driving behavior and control vehicle trajectories, which have been greatly constrained by human limits in existing manually-driven highway traffic. Understanding and modeling automated vehicle "driving" behavior is critical to evaluating transportation system performance under different CAV deployment scenarios. There is a general CAV analysis, modeling and simulation (CAV AMS) framework currently under development by Federal Highway Administration (FHWA). The framework focuses on both the demand-side and supply-side impacts of AVs. The data needs and available datasets to calibrate the models resulting from such framework are identified. Some data collection efforts through field experiments using CAVs and connected infrastructure at the FHWA Saxton Transportation Operations Lab are made [3]. For example, the infrastructure to vehicle (I2V) communication data specified an eco-drive mode, optimizing fuel consumption by giving speed and powertrain commands to CAVs. Data collection efforts involved 5 vehicles with Cellular/LTE, corrected GPS, and using Dedicated Short Range Communication (DSRC) systems. Several sensors were used to estimate speeds, fuel consumption, and braking. Another field experiment was conducted on Interstate I-66, Virginia, USA. The goal was to create a rolling block of 3 AVs to smooth traffic behind. Indeed, the lead probe vehicle experienced much greater speed oscillations than probe vehicles behind the AV block. Other vehicle-to-vehicle (V2V) controls developed include a protocol for vehicles to merge into Cooperative Adaptive Cruise Control (CACC) strings. Some eco-approaches and departures at signalized intersections were found to reduce fuel consumption by slowing down or accelerating vehicles to avoid complete stops. Overall, a significant amount of data is

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[2] By Jiaqi Ma, Leidos Inc.

being generated. However, more data is needed and limited numbers of AVs are available. Hardware-in-the-loop testing could be used to combine real data collection with simulation [4]. CAVs will need new types of tools and controls, and data is needed to calibrate key model components.

2.3 Recent Findings from Micro-simulation of Traffic Impacts of Cooperative Longitudinal Control Systems[3]

Some efforts have been made to simulate the microscopic interactions between manually driven vehicles and vehicles that use automatic longitudinal control systems, both autonomous (ACC) and cooperative (CACC) [5]. The models representing the automated car following behavior of the ACC and CACC systems are derived directly from the experimental responses of full-scale vehicles equipped with these systems, so they are much more realistic than previous theoretical models that have over-estimated traffic flow benefits of ACC. The models of manual driving include details of lane changing interactions on multi-lane highways and have been calibrated using field data from a complex freeway corridor. Results from the simulation performed by the PATH research group show the effects on highway throughput of various operational strategies including both continuous and limited access managed lanes for the equipped vehicles, limitations on discretionary lane changing, and limitations on the lengths of coordinated strings of vehicles, with varying levels of on-ramp and off-ramp traffic and for various market penetrations of equipped vehicles.

It should be noted that other microsimulation models used to analyze CAV or AV impacts on longitudinal traffic characteristics do not reflect actual ACC and CACC behavior. Drivers have several modes of manual driving with different combinations of lane changing and car following behaviors. To calibrate the models used in the PATH research presented in this section, 4 identical Nissan AVs were used to develop the microsimulation models of ACC and CACC. Extensive data were collected for the calibration task on the Sacramento SR-99 freeway. ACC and CACC modes were added to the manual driving modes. The ACC incorporation caused worse shockwaves than the manual driving. The shockwaves took approximately 5 s to propagate upstream through 4 vehicles. The reason behind such finding may be attributed to the fact that human drivers look more than one vehicle ahead (i.e. the look-ahead factor). With the incorporation of CACC, cars accelerate and decelerate together, which reduces the magnitude of oscillations when the shock-wave propagates backwards. In other words, communications play a key role in the AV efficiency.

A variety of additional experiments were performed on a highway network segment, with variables of on-ramp and off-ramp volume, CACC minimum gap,

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[3] By Steven Shladover, PATH, UC Berkeley.

and AV market penetration. Overall, the roadway flow capacity increased with CACC market penetration. On-ramp volume decreased the downstream throughput. Off-ramp volume also reduced the main throughput with managed lanes due to vehicles weaving from the managed lanes to the exit ramps. The CACC reduced discretionary lane changing because it is often preferable to remain in a CACC string than change to a slightly faster lane.

In summary, the effects of ACC and CACC are noticeable but subtle. The modeling and simulation results may be feasible and interpretable; however, such results require careful calibration of microsimulation with real testing before being considered as definitive and suitable to design CAV related policies.

2.4 Control of Traffic with a Small Number of AVs[4]

Traffic control via mobile actuation is now viable thanks to recent and significant improvements in self-driving and connected vehicle technologies, and may offer new traffic management opportunities beyond today's fixed control systems such as variable speed limits. Traffic is already transitioning from fixed sensors and controls (e.g. loop detectors and traffic signals) to mobile sensors and controls (sensing through AVs, and using AVs to control traffic stream). Mobile sensing is already available through cell phones, and the next step is mobile control. In line of such developments, experimental evidence suggests that careful control of a small number of autonomous vehicles through mobile control in the traffic stream is sufficient to completely eliminate "phantom" traffic jams caused by human driving. Accordingly, a seminal demonstration was conducted by the Mathematical Society of Traffic Flow, in which 22 human-driven vehicles that initially drive smoothly around a circular track eventually degrade into substantial stop-and-go traffic [6]. These experiments resolved a long-standing discussion in transportation science, namely that traffic waves can in fact arise without any external causes, but did not offer a solution to prevent it. The 22 vehicle experiments were repeated with the modification that one intelligently controlled autonomous vehicle replaced a single human-piloted vehicle. A series of experiments in Tucson, Arizona were conducted to measure the influence of the carefully controlled AV on human-piloted vehicles. The main experimental result indicates that even when the penetration rate of autonomous vehicles is as low as 5%, stop and go traffic can be eliminated.

The AV speed control reduced braking events by 98.6%, the standard deviation of speed by 80.8%, and fuel consumption by 42.5%. The elimination of waves allows significant improvements in the total traffic fuel efficiency and safety, and is achievable long before the majority of vehicles are automated. It should be noted however that finding the optimal parameters for mobile control is still open—a parameter sweep was used for the results presented earlier. There is some

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[4] By Daniel Work, University of Illinois at Urbana Champaign.

disconnect from the mathematics and *simulations* to the actual controllers due to the need for a safe gap to avoid real collisions. Moreover, in real life driving conditions, more than 5% AV market penetration may be needed to realize improvements in traffic flow mobility, safety and sustainability.

3 Discussion

The panel discussion (including audience interaction) identified the key challenges in traffic flow research in terms of data needs to calibrate and validate existing traffic flow models *involving* CAV/AV technologies:

1. *Data availability, cost and intellectual property*: Data collection for a variety of vehicles is needed. Each manufacturer will develop a separate ACC and CACC system, and even different vehicle models from the same manufacturer will behave differently. Researchers currently use simple models due to the difficulty and expense of obtaining real data. Companies are reluctant to make available their vehicles or even their ACC logic because they risk reverse engineering proprietary software through observation of powertrain commands.
2. *Human behavior*: Another research challenge is associated with human behavior; ironically, estimating the effects of AVs during the transitionary period of deploying AVs/CAVs requires more accurate modeling of human driving. Dr. Steve Shladover's study spent almost 75% of the effort calibrating the human driving model. As an illustration of such challenge along with the need to collect more data on human behavior, ACC minimum safe gaps for reverting to human control often seem quite low—for instance 0.6 s headways on free-ways. However, test subjects were generally comfortable with such gaps (although longer time headways would be needed on roads with lower speeds).
3. *Platooning logic versus automation*: Platooning plays a key role in the performance of AVs/CAVs but limited research has focused on this aspect of automation and communication between vehicles. For example, CACC systems differ from platooning systems in several ways. In platoons, the lead vehicle typically has a supervisory role for vehicles entering and leaving, whereas CACC string formation is more ad hoc. Also, current CACC systems often use constant time gap headways whereas platooning systems use constant clearance distances.
4. *Vehicle dynamics and communication specifications*: Models should include vehicle dynamics and receipt and response to communications. Including communications models of radio-wave propagation is not valuable—it is too dependent on the physical environment and not transferrable to other roads. Including message loss/delay functions without the under-lying causes is not sufficient.

In line of the above challenges and limitations, the panel suggests the following road map:

1. *Leveraging existing available data for CAV modeling and evaluation*: Existing, or currently available AV technologies, should be used for data collection. Although future opportunities may offer better data collection, current technologies supported by non-automotive companies allow avoiding extensive development costs. Moreover, standard fixed sensors and controls are better suited for some types of data collection and traffic control if compared to more "aggressive" new technologies.
2. *Further focus on freight transportation stakeholders*: Other types of AV applications, such as freight, are more economically driven. AVs are in consideration for railroads because of the associated reduction in operation cost. Part of the large infrastructure costs for freight transport should be directed towards modeling the freight traffic flow and the AV economic impacts.
3. *Guidance rather than prescriptive role-playing by the research community*: Research models are unlikely to be implemented or adopted directly by automative companies. However, CAV research can illustrate errors or issues for companies, such as the benefits of one type of longitudinal controller. Forums for technology transfer from researchers to industry should focus on the main ideas and lessons from experiments but not the details. Social scientist researchers may be more in tune with human factors than engineering models. For instance, a widely-cited model for ACC was ineffective when actually used on the road.
4. *Common research oriented test-bed and further coordination*: Development of common testbeds and data is a major issue that needs to be addressed by public agencies providing support to CAV research and by academicians. Sharing data with other researchers requires considerable expense for documentation and support. Data confidentiality becomes an issue as well. Such challenges may be overcome if a more elaborate partnership is established between the public and the academic sector in the United States (US) and abroad.

In conclusion, the panel along with the AHB45(3) Subcommittee recommends developing a partnerships with companies developing AVs to test and collect data. Further efforts are needed by the research community to educate the public on mobile control. For example, drivers may become angry or frustrated at vehicles implementing speed harmonization if they do not understand the benefits to congestion. Additional initiatives by the public agencies are needed with the aim of allocating funding in open AV tests for documenting and sharing data. The results may facilitate creating a forum for sharing main lessons and ideas with AV manufacturers without being involved in the corresponding administrative and legal details.

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Making Automation Work for Cities: Impacts and Policy Responses

Dirk Heinrichs, Siegfried Rupprecht and Scott Smith

Abstract There seems to be great concern and perhaps even greater uncertainty about how autonomous vehicles (AV) in cities may possibly affect not only mobility and transport but also infrastructure, land use, and the natural environment. Along with the debate on the impacts of AV the question arises what urban and transport planning strategies will be needed to ensure that the transition towards a fully automated transport in urban areas will contribute in the best possible way to urban sustainability goals and make it compatible with existing key urban policies. This paper addresses the question: What do city planners and policy makers have to know about the technology, its impacts and how can they prepare? It reviews the status of planning and implementing automation in cities and metropolitan areas in the US and in Europe. The paper draws on the presentations, discussions and conclusions from a breakout session 'Making automation work for cities' at the Automated Vehicle Symposium in July 2017.

Keywords Autonomous vehicles · Urban planning · Cities · Transport
Land use · Strategies

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1 Introduction

Autonomous driving has started to receive attention not only by the research community but also by planning practitioners and policy makers concerned with transport and urban planning. There seems to be great concern and perhaps even greater uncertainty about how autonomous vehicles (AV) in cities may possibly affect not only mobility and transport but also infrastructure, land use, and the natural environment. This debate on the impacts of AV has raised concerns about what urban and transport planning strategies will be needed to ensure that the transition towards a fully automated transport in urban areas will contribute in the best possible way to urban sustainability goals and make it compatible with existing key urban policies.

This paper responds to these needs. It addresses the question: What do city planners and policy makers have to know about the technology, its impacts and how can they prepare? To find answers it draws on the presentations, discussions and the synthesis of a special breakout session at the Automated Vehicle Symposium (AVS) 2017, which brought together about 30 experts from practice and research.

Following the contents of the session, this paper reviews the status of planning and implementing automation in cities and metropolitan areas in the US and in Europe. The paper firstly provides a structured overview of different forms and options of AV technology application in cities and summarizes the current state of prediction about their deployment. In addition to the most commonly discussed options of private automated vehicles and flexible fleets of so-called ‘robotaxis’, the overview includes applications for urban services, freight and novel options for integrating flexible services into public transport. Secondly, the paper discusses expected impacts of AV in cities. Aside from direct impacts on mobility decisions and behavior, we also review indirect effects. Thirdly, the paper explores concrete case experience in cities where AV technology is currently being implemented in the form of pilot and demonstration projects. These cases provide valuable insights for creating an enabling policy framework for transport automation that also contributes to meeting key urban policy goals. A concluding section pulls together the findings from the previous sections and suggests key action fields to urban planners and policy makers for making automation work for their cities.

2 AV Technology Application in Cities: Options and Deployment Scenarios

While high levels of automation technologies in transport can already be found in aviation, maritime transport and rail-based public transport systems, road transport has yet to reach a high degree of automation. This is equally true for private vehicles and public transport vehicles. One reason is that navigating on roads requires much more complex interaction with other users.

However, this is starting to change. Despite the technological challenges that need to be overcome before AVs become a reality on public roads, the degree of automation in road vehicles is continuously rising. Advanced driver-assistance systems, such as lane-keeping assistants and adaptive cruise control, are already available in currently produced vehicles, and this is moving the technology development forward. Most major car manufacturers already market and sell high-end vehicles with features like automated braking, self-parking, lane-departure warning, and variable-speed cruise control. Most are also racing to develop fully autonomous vehicles. In addition, there are other applications under way. Cities like Boston or Singapore are currently testing fleets of driverless taxi vehicles. And European Union–funded projects (e.g. CityMobil1 and 2, CoExist) have already begun testing driverless transit on public streets or explore applications for freight and public services like garbage removal.

These examples illustrate that the diffusion of AV technology in urban transport systems is unfolding for many different applications and along different deployment scenarios. Three main scenarios have been identified [1]. A first scenario is the steady increase in the use of advanced driver assistance systems followed by successive steps towards vehicle automation and a corresponding reduction in the driver's responsibilities. This is labelled as "evolutionary scenario". The car industry is currently launching a range of systems that automates both longitudinal (acceleration, braking) and lateral control (steering), with driver monitoring still to be introduced—in other words, a partially automated system. A second pathway, the "revolutionary scenario" does not pursue such a continuous improvement of driver assistance towards automated driving, but rather a disruptive leap straight from today's traffic pattern, with human-driven vehicles, into a scenario in which the driver hands over control to the system completely. One credible possibility could be the introduction of vehicles and services like those being tested in Boston and Singapore with higher-order automation as competitors of conventional taxis. A third deployment scenario for automated driving involves implementing transportation paradigms that provide slow-moving passenger vehicles, for example in urban areas like those tested in the city of Helmond in the Netherlands, Milton Keynes and elsewhere. Users would call such vehicles using a smartphone app and ride them over relatively short distances. These transportation solutions would compete with conventional taxis but be more affordable, comfortable, and innovative from the standpoints of both users and operators. Such automated mobility on demand (AMOD) systems represent an individualization of public transportation as a "transformative scenario" for traffic in urban areas.

While current announcements by the industry claim to bring autonomous vehicles to the market within the next few years (while being vague on the intended levels of automation), it is hardly possible to make predictions beyond the target date of 2020 in particular with respect to the revolutionary and transformative deployment scenarios. A few roadmaps exist (e.g. [2–5]) showing the expectations when fully automated vehicles will be available in urban environments. With respect to the evolutionary scenario, they expect that higher order automation in the form of an urban and suburban pilot will be ready by 2026 [2] and fully automated vehicle should be able to handle all driving from point A to B without any input from the passenger driverless cars with no driver backup in 2030 [2, 5] provided that legal frameworks are in place [3]. Similar expectations exist for the revolutionary and transformative scenarios. Automated taxis are expected to operate from 2030 onwards [2, 4]. The same projection exists for AMOD services that would operate on their own exclusive infrastructure [2].

City managers and planners will play a strong role in shaping the advancement of automated driving in urban areas. Already now, they are crucial as benchmark setting “local champions”. And they’ll create regulatory and liability structures that advance or impede new technologies, may it be by enacted laws that favor autonomous cars or building out communication networks in part to accelerate the development of connected cars.

3 Impacts of AVs in Urban Areas

Several authors [6–8] have developed frameworks of AV impacts. Following [8, 9] we divide impacts into two major groups: direct and indirect. Figure 1 depicts the impact areas and their respective linkages. Direct impacts are those which have a relatively clear cause-effect relationship with the primary activity or action. They are generally easier to capture, measure and assess, and are often (though not always) immediate to short-term in nature. In Fig. 1 they are in the upper left,

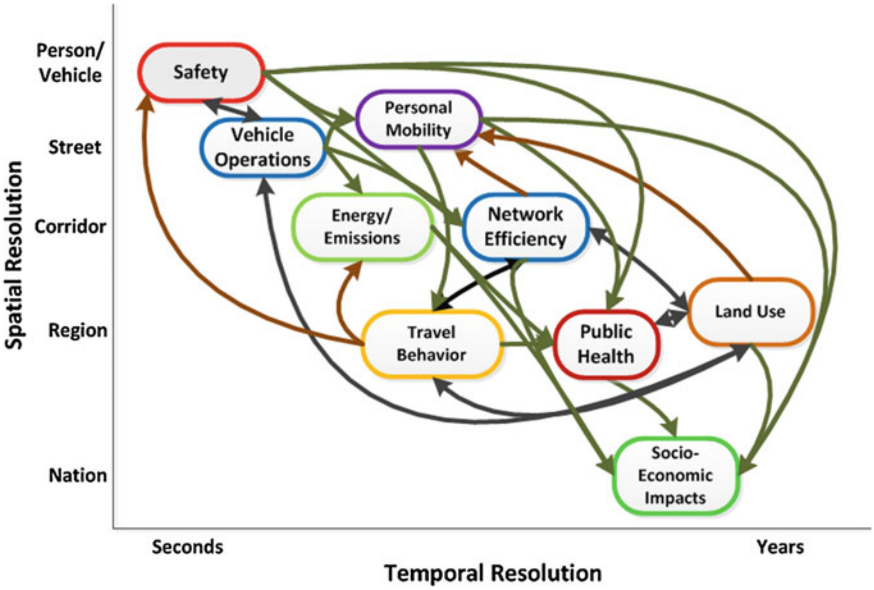

Fig. 1 AV impact areas and their respective linkages

and include safety, vehicle operations, energy/emissions, and personal mobility. Indirect impacts summarize the broader effects of the individual direct impacts and are produced as the result of a path/chain of impacts, often with complex interactions and external factors. They are typically more difficult to measure and are longer than the time horizon of a field test.

Examples of **direct** impacts include the response of vehicle occupants and other road users, safety, vehicle operations (e.g., acceleration, car following, gap acceptance), energy/emissions, personal mobility (e.g., the ability of persons, including non-motorists and persons with disabilities, to travel). Finally, the capital and operating costs of the system are important, for understanding likely future deployment.

Specific areas of **indirect** impact include the following:

Network Efficiency, which refers to lane, link, and intersection capacity and throughput in a regional transport network. It also refers to travel time and travel time reliability.

Travel Behavior: A traveler may respond to AV options, including new service offerings, by changing travel behavior. There may be more or fewer trips. Modes, routes, and destinations may change.

Public Health: Automation may impact the health (physical and mental) of individuals and entire communities via safety, air pollution, amount of walking and bicycling, as well as access to medical care, food, employment, education, and recreation.

Land Use: Automation may affect the use of land for transport functions (e.g., parking, road geometry). Longer term land use changes may include community planning, i.e., location and density of housing, road network design, employment, and recreation.

Socio-Economic Impacts: Improved safety, use of time, freight movement, travel options (for motorists and non-motorists), public health, land use, and effects of changed will have longer-term economic impacts. Automation may also have substantial impacts on labor markets and industries.

In assessing indirect impacts, note that fleet composition and service offerings might change, for example:

- Vehicle ownership might change. For example, there may be greater use of shared vehicles, which will affect the amount of land required for parking.
- Better crash avoidance may enable the use of lighter-weight vehicles (affects material and energy use or emissions) and prevent crash-related congestion (affects network efficiency).
- The advanced control systems used for automation may also contribute to electrification (affects energy use and emissions).
- If there is no human driver, the layout of the vehicle might change (affects energy use).

- Without the labor cost of a human driver, it may become economical to use smaller vehicles for both trucking and transit (affects energy use and network efficiency).

Finally, several uncertainty factors will affect the impacts of AVs [10]:

- Policy factors include law/legislation, risk, cost structure and infrastructure (right-of-way).
- Technology factors include those that affect cost and the operational design domain, including sensor/control system performance, security, communications needs and ability to handle the unexpected.
- User factors include willingness to share vehicles, trips and data, willingness to cede control, value-of-time (multi-tasking) and the response of other road users to the presence of automation.

All of these impacts are important in urban areas. Particularly important are the safety of interaction between AVs and non-motorized users (pedestrians and bicyclists), impacts on road congestion, and impacts on land use, as urban land is usually valuable.

4 How Cities Prepare: A Review of Ongoing Initiatives

As outlined above, city initiatives and demonstration and research projects are under way in various locations. More recently, they have been complemented by initiatives of Networks of Cities with the attempt to derive broader insights and orientation for policy and action.

Among cities, an increasingly consistent set of common themes is emerging from first (limited) pilots and local stakeholder dialogues:

- City goals first: While most of the first pilots focused on proving technical feasibility and many decision-makers used the publicity around those tests to promote their cities as forward-looking and innovative places of investment, there is now widespread agreement that automation must contribute to meeting key urban development goals in order to justify public support and investment. Although this is accepted in general, very few cities have actually included automation in the development strategies.
- AV-Sharing is the preferred model: There is growing awareness that automation may lead to an increase in vehicle miles travelled and may cannibalize mainstream transit services. To prevent this, many transit agencies follow a strategy of “transit first” also in the automation context by focusing on models that promote shared use of automated vehicles.
- Public engagement is important: public acceptance of automation is difficult to measure theoretically, but there is clear indication (e.g. from Boston, San Francisco and Milton Keynes in the session) that citizens may be supportive if

they get better access, increased safety, higher reliability. Involving the public, therefore, appears to be an important precondition for successful implementation.
- Working in cooperation: Automation-based services can be very disruptive (in a positive or in a negative sense). There was agreement in the session that cities should lead a collaborative, multi-stakeholder process where public and private stakeholders coordinate technology and service deployment and policy development/planning.
- Upscaling is the next challenge: Moving from technical showcases to pilots that involve real users on public roads is a wide step. As the example from Helmond and other cities shows, financing, service and infrastructure integration post new challenges.

The process of formulating common positions on automation and urban development is facilitated by associations like National Association of City Transportation Officials (NACTO) in the US and POLIS in Europe. The NACTO represents a City network in the U.S. NACTO has recently launched its Blueprint for Autonomous Urbanism. This Blueprint outlines a vision for cities in a future where automated transportation is both accepted and widespread as part of the built environment. It is a human-oriented vision for the potential of city streets, intersections, and networks-one in which automation can serve the goals of safety, equity, public health, and sustainability [11].

The blueprint endeavors first and foremost to illustrate policy goals using renderings and diagrams, and to present an alternative vision of the future oriented around city streets as public spaces. Cities need strong policies to guide the future of automation and to help communities shape powerful technologies around their goals, rather than the other way around. Clearly articulated policy goals represent a good first step for cities. Achieving these goals will require creative public private partnerships, adaptive decision making, and critical data sharing agreements.

In concrete terms, for NACTO making automated vehicles work for cities rests on a set of main pillars:

- Redesign of streets and intersections for people, not vehicles.
- Design for safety: new rules on the road including setting safe speed limits, safe and frequent crossings, attention to cycling through intersections.
- Embracing new mobility systems: expanding transit, with high ridership transit as a backbone, flexible services to connect point-to-point, creating a new mobility network.
- Curbside management: utilize the gradual disappearance of street parking and manage the immense public asset represented by the curb for multiple and flexible purposes.

POLIS is an association of 70 (mostly) European cities and regions is developing its view on automated vehicles. In a situation where unrealistic expectations about the likely impact and availability of automated vehicles are created, many cities want to be the first to have automated vehicles on the roads, while many city managers fear the unknown effects. POLIS, therefore, intends to raise awareness and promote reflection about AVs among local and regional authorities, communicate views of cities and regions to policy makers and other AV players, and challenge the AV sector to develop products and services suited to urban context. Possible implications of automation include travel behavior, spatial, social, road safety, traffic efficiency, and investment impacts. Local/regional authorities need to determine the point on a spectrum where AVs can deliver most benefit to their city/region and develop policies accordingly. Cities need to explore urban planning and development, specific automated services, safety of vulnerable road users, travel behavior changes and traffic management implications.

POLIS is currently preparing a position paper on automation. Some preliminary recommendations include:

- City and regional authorities should build and implement AV policies to guide their introduction in the most effective manner.
- A structured dialogue between the public sector and AV industry needs to be established.
- Research on the potential impacts of AV on urban and regional transport is needed (travel behavior, vulnerable road user interaction and safety, infrastructure implications, new transportation services, etc.).
- EU and national policy on AV should give greater consideration to sustainable urban mobility policy.

In the U.S. regional planning organizations have engaged in exploratory analysis of the potential effects to automation on a metropolitan area's transportation system (for example [10]). The National Cooperative Highway Research Program (NCHRP) Project 20-102 has funded several research tasks to support planners and policy-makers. A U.S. C/AV analysis modeling and simulation (AMS) project is providing a framework and models for the effects of C/AV applications. This project is twinned with the European Horizon 2020 CoEXist project, which is developing simulation tools for a mix of automated and non-automated vehicles in several European cities and developing a "automation readiness" concept for transport authorities and infrastructure owners. Both projects are cooperating to develop a common representation of automated vehicles in major transport simulation models.

5 Making Automation Work for Cities: Towards an Action Agenda

In conclusion, what do city planners and policy makers have to know about the technology, its impacts and how can they prepare? The previous discussions highlight that cities and their networks are becoming active players in seeking ways to shape AV technologies around their goals, despite (as highlighted in Sect. 3) the various uncertainties that exist. It also becomes obvious that the current round of experimentation attends to all of the alternative (or complementary) deployment scenarios: evolutionary, revolutionary and transformative. A few key learnings can be derived from these insights.

Firstly, penetration of AV technology in cities is happening but at slow pace and the applications and use cases are diverse. As automation is a new topic for most cities, it needs joint efforts. Networking of approaches and experiences is indispensable to speed up knowledge exchange. Secondly, cities are motivated by very similar goals. These emphasize improving safety, inclusion/access and mobility for all citizens. There are equity concerns whereby AVs are not intended solely for the wealthy population. Across cases, there is a strong interest in supporting walking, cycling and transit. This reflects a thinking that goes beyond a single mode of transport but one that considers the potential of AV technology to innovate the entire transport network and that considers the integration of modes. Thirdly, there is the need to involve a wide range of stakeholders including citizens. They should understand that tests are innovation pilots, not yet regular services. A major challenge is how to organize the involvement process. Approaches to stakeholder participation are more a "social experiment" than technical approaches. Both approaches should coexist and need to learn from each other. Finally, cities need to work closely with OEMs and technology providers who are looking for new markets and are interested in testing and demonstrations in cities.

What should policy makers in cities do to create an enabling policy framework for transport automation that also contributes to meeting key urban policy goals?

A first set of actions concerns the task to put in place basic "automation readiness" criteria. This involves setting widely supported policy goals, expected CAV contributions and creating a strong multi-stakeholder partnership (private-public, public-public, between departments, state/national support).

A second set of actions concerning moving ahead with implementation. The case experience suggests a lightweight, incremental approach that systematically builds critical mass and manages (complex/contradictory) citizen expectations. A communication that frames implementation as innovation can be a key for success. Implementing automation also means thinking about the business case. Again, the experience shows that application can be manifold and can involve public transport as well as other municipal services (e.g., waste collection, street cleaning, snow plowing). As there is yet little knowledge on effects, thinking about impact assessment from "from day 1" and identifying clear performance measures for automated services/providers (local KPIs) are important, as is clarifying expectations on users' cross-brand experiences (or a uniform local brand?). Given the possible implications of AV deployment on urban space, space management is a key future challenge (on-street/off-street).

A third set of actions concerns the wider context of automation and innovation. This includes ensuring that automation is part of an innovation cycle (including learning) and synchronizing technology and policy transition. In other words, cities planners and policy makers need to "upgrade" their strategies in line with the new mobility paradigm that the technology involves. This also includes considering the wider transition landscape of influencing factors (Mobility as a Service, digital infrastructure, energy, etc.) and how supporting ecosystems can contribute (e.g. planning, labor relations, procurement). Finally engaging in learning and exchange activities, including international dialogue, scales up the learning process.

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Correction to: Research to Examine Behavioral Responses to Automated Vehicles

Johanna Zmud, Felipe Dias, Patricia Lavieri, Chandra Bhat, Ram Pendyala, Yoram Shiftan, Maren Outwater and Barbara Lenz

Correction to:
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The original version of the book was inadvertently published with misspelt co-author name "Felipe Diaz" which has been now corrected to read as "Felipe Dias" in chapter "Research to Examine Behavioral Responses to Automated Vehicles". The correction chapter and the book have been updated with the change.

The updated online version of this chapter can be found at
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