Introduction: The Automated Vehicles Symposium 2017

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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.