

TRANSPORTATION RESEARCH

CIRCULAR

Number E-C232

April 2018

AUTOMATED VEHICLES SYMPOSIUM 2017[®]

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TRANSPORTATION RESEARCH CIRCULAR E-C232

Automated Vehicles Symposium 2017

Summary of a Symposium

July 11–13, 2017
Hilton San Francisco Union Square
San Francisco, CA

Cosponsored by
Transportation Research Board of the National Academies of Sciences, Engineering, and
Medicine
Association for Unmanned Vehicle Systems International

Proceedings Prepared by
Texas A&M Transportation Institute

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500 Fifth Street NW
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The **Transportation Research Board** is one of seven major programs of the National Academies of Sciences, Engineering, and Medicine. The mission of the Transportation Research Board is to provide leadership in transportation innovation and progress through research and information exchange, conducted within a setting that is objective, interdisciplinary, and multimodal.

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Automated Vehicles Symposium 2017

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Preface

SYMPOSIUM OVERVIEW

The 2017 Automated Vehicle Symposium (AVS) was held in San Francisco, California, on July 11–13, 2017. The symposium was organized and conducted through a partnership between the Transportation Research Board (TRB) of the National Academies of Sciences, Engineering, and Medicine and the Association for Unmanned Vehicle Systems International (AUVSI). The symposium featured keynote speakers, presentations on current projects and programs, 25 concurrent breakout sessions, poster sessions, the enterprise solution series, and ancillary meetings.

The development, testing, building, and deployment of autonomous vehicles (AVs) continues at a rapid pace. These technologies will have a major impact on transportation safety and mobility, as well as the environment and urban forms. The introduction of these technologies also has the potential to disrupt the transportation system.

The 2017 AVS provided the opportunity for communication, collaboration, and information sharing on a wide range of topics, including potential public policy, safety and security, ethical, and equity concerns, as well as technology innovations and applications. The 2017 AVS attracted 1,488 participants from the United States and other countries. The growth in attendance from 2013 to 2017 reflects the increased interest in connected and automated vehicles (CAVs) and AVs. Approximately 250 people attended the first symposium in 2013.

Attendees at the 2017 AVS represented a wide range of public agencies and private-sector groups. Individuals from federal, state, regional, metropolitan, and local agencies participated in the symposium as did representatives from technology and software companies, automotive original equipment manufacturers (OEMs), and Tier 1 suppliers, consulting firms, and other industries. Researchers and faculty from universities and research institutes, as well as from nonprofit organizations and other groups also participated in the symposium.

REPORT ORGANIZATION

This report presents the proceedings from the 2017 AVS. The report follows the general symposium agenda. The presentations by speakers in the general sessions are summarized, including the highlights from the 25 breakout sessions. A list of the posters presented in two sessions is provided. The appendices provide a description of the key topics covered in the breakout sessions.

The preparation of this report was supported by TRB. The views expressed in this summary are those of the individual speakers and discussants, as attributed to them, and do not necessarily represent the consensus views of the symposium participants, the volunteer organizers, the TRB, or the National Academies of Sciences, Engineering, and Medicine. Some of the symposium speakers provided their PowerPoints or other supporting materials, which are available at <http://www.automatedvehiclessymposium.org/avs2017/program/proceedings>.

EDITOR'S NOTE

The organizers of the Automated Vehicles Symposium 2017 endorse the term “automated” in reference to vehicles that have advanced driving capabilities, rather than the term autonomous. However, the terminology in these proceedings remain faithful to the speakers’ own words, and so retain the terms “self-driving,” “autonomous,” and “automated,” according to the speakers’ or authors’ original choice.

PUBLISHER'S NOTE

The preparation of this report was supported by TRB. The views expressed in this summary are those of the individual speakers and discussants, as attributed to them, and do not necessarily represent the consensus views of the symposium participants, the volunteer organizers, TRB, or the National Academies of Sciences, Engineering, and Medicine. This e-circular has not been subjected to the formal TRB peer-review process.

Welcome from the Association for Unmanned Vehicle Systems International

BRIAN WYNNE

Association for Unmanned Vehicle Systems International

Brian Wynne provided a welcome from AUVSI. He described the partnership with the TRB in hosting the 2017 AVS, AUVSI activities, and efforts at the national level focusing on regulations for self-driving vehicles.

Wynne noted that 2017 is the fourth year AUVSI has partnered with the TRB to develop the industry's most comprehensive, diverse, and largest global event dedicated to addressing AVs, the technologies that are enabling them, and the myriad of issues impacting their deployment. He highlighted the growth of this event, which began with just a few hundred people in 2014. The 2017 AVS brings together more companies, policy-makers, educators, and researchers than ever before. Wynne suggested that the growth and interest in the symposium provided a testament to the tremendous opportunity for AV technologies and the industry.

Wynne described AUVSI, which is the world's largest nonprofit organization dedicated to the advancement of unmanned systems and robotics. He noted that AUVSI has been the voice of unmanned systems for more than 44 years. AUVSI represents more than 7,500 members, including more than 600 corporate members from more than 60 countries. Additionally, AUVSI has a diverse membership from industry, government, and academia.

Wynne discussed that AUVSI focuses on air, ground, and maritime unmanned systems, along with the common underlying technologies that crossover all those domains. He noted that AUVSI advances the unmanned systems and robotics community through advocacy, education, and leadership.

Wynne described AUVSI's role in AVs. He reviewed the U.S. Senate Committee on Commerce, Science, and Transportation principles for bipartisan legislation on self-driving vehicles, which were released in June 2017. The principles include promoting continued innovation and reducing existing roadblocks, reinforcing separate federal and state roles, and encouraging the responsible adoption of self-driving vehicles. Wynne noted that the House Energy and Commerce Committee has also outlined several legislative proposals to foster investment and innovation in AVs. The committee is reviewing policies associated with testing guidelines, infrastructure development, and data sharing.

Wynne commented that while legislation is still under development, lawmakers have indicated that they will direct strong federal leadership that ensures safe self-driving vehicles on the road, and reduces regulatory conflicts for the safe and rapid testing and deployment of this transformative technology. He suggested that Congress recognizes that AVs can potentially save tens of thousands of lives on the nation's highways every year, as well as improve mobility and spur enormous economic activity.

Wynne reported that AUVSI recently formed a working group for members engaged in unmanned ground systems and AVs. He noted that AUVSI would continue monitoring developments in Washington and at the state level to provide opportunities for members to share their experience and expertise with policymakers.

In concluding, Wynne recognized and thanked TRB, the 2017 Symposium Executive Committee, and all the volunteers and organizers who dedicated their personal time to making

the symposium a success. He encouraged participants to visit with the exhibitors and benefactors. He also thanked all of the participants for attending the symposium and for taking an active role in shaping the future of transportation.

Welcome from the 2017 Symposium Executive Committee

JANE LAPPIN

Toyota Research Institute

Jane Lappin provided a welcome to the world's oldest, largest, and most diverse AVS on behalf of the 2017 Symposium Executive Committee and the 150 volunteer organizers who produced this meeting.

Lappin noted that AVs will bring great safety and mobility benefits to society, but they will also bring complex challenges, none of which can be solved by any one business sector or government entity alone. She highlighted the AVS mission, which is to convene academia, government, and industries, from across the country and around the world to address these critical cross-cutting issues.

Lappin reported that planning for the 2017 AVS began at the TRB Annual Meeting in January. Breakout session topics were nominated by organizers based on their TRB committee's various perspectives and expertise. Plenary topics and breakout sessions were vetted and developed through consensus by the AVS Executive Committee. She noted that while themes often continue from year to year, the content changes apace with current developments. She commented that AVS registration fees are intentionally kept as low as possible to enable students and personnel from nonprofit organizations and government agencies to participate. Corporate benefactors help offset the symposium cost, and everyone pays the registration fee.

Lappin stated that 2017 was another record-breaking year for the AVS. The first symposium was held in 2012 with 125 attendees. As of the first day of the 2017 symposium, 1,500 people had registered for the 2017 AVS. Lappin noted the growth in innovation and private investment in AVs that has occurred in the 6-year period, as well as explosive growth in media coverage. She further noted that national and regional governments continue investing hundreds of millions of euros, yen, renminbi, won, bitcoin, and dollars in policy-related research and vehicle testing.

Lappin discussed the high levels of legislative activity among states and at the national level related to AVs and self-driving cars. In 2012, six states introduced AV legislation. In 2013, nine states and the District of Columbia introduced legislation. The numbers have continued to increase, with 12 states in 2014, 16 states in 2015, 20 states in 2016, and 33 states thus far in 2017. Further, some states, have introduced multiple laws.

Lappin noted that the U.S. Senate Committee on Commerce, Science, and Transportation has put forward a bill that would preempt some of the states' activities. There are also 14 bills proposed from the U.S. House of Representatives' Energy and Commerce Committee. U.S. Department of Transportation (DOT) Secretary Chao has directed the National Highway Traffic Safety Administration (NHTSA) to speedily produce the next version of the AV guidance quickly. Lappin reported that the AVS 2017 policy and law breakout sessions would be discussing this surge of activity.

Lappin described the increased activity in the United States around the development of test beds, and the designation of 10 Automated Vehicle Proving Grounds to Encourage Testing of New Technologies. She noted that information on the U.S. DOT programs would be presented in the international test bed breakout session, in the U.S. DOT and U.S. Department of Energy (DOE) plenary talks, and during the U.S. DOT listening session on Thursday afternoon.

Lappin reported that the 2017 AVS includes 25 policy, operations, and technical breakout sessions and two commercial sessions on enterprise solutions. She noted that any one of these sessions would stand alone as a worthwhile workshop. There will be a lightning round of report-outs on the breakout sessions Wednesday and Thursday mornings. Additionally, the PowerPoints from the general and breakout sessions will be available on the conference website in the next 2 weeks and written proceedings will be available from TRB later this year.

Lappin reported that AVS is an independent, noncommercial meeting, produced through a partnership between TRB and AUVSI. She noted that the TRB and AUVSI partnership on the AVS provides their shared constituency with one large diverse international destination for learning, networking, exchanging insights, making progress, and making deals. Lappin reported that the 2017 AVS broke records for benefactor contributions and she thanked all the sponsoring companies.

Lappin also thanked the symposium speakers who traveled and registered at their own expense and the 150 volunteers who produced this meeting. She especially recognized Lindsay Voss and Karissa Bingham, and the entire AUVSI team for truly excellent meeting planning and production. Lappin closed by thanking all the participants for contributing their expertise to the discussions and further enriching the understanding of the promise and challenge of road vehicle automation.

Caltrans Leadership in Automated Vehicle Research

MALCOLM DOUGHERTY

California Department of Transportation

Malcolm Dougherty welcomed participants to California and San Francisco on behalf of Governor Jerry Brown, the state of California, and the California Department of Transportation (Caltrans). He noted that California was proud to host the 6th annual symposium, with the participation of numerous national and international subject matter experts. He highlighted Caltrans involvement in AV research and testing, and discussed recent activities underway in the state.

Dougherty described the recently enacted Senate Bill 1, which provides more than \$50 billion for improvements to California's transportation infrastructure over the next 10 years, including increased funding for the State Highway System. Senate Bill 1 includes \$15 billion for state highway maintenance and rehabilitation, \$4 billion for bridge and culvert maintenance and rehabilitation, \$3 billion for high-priority freight corridors, and \$2.5 billion for congested corridor relief.

Dougherty discussed the potential benefits from AVs for large infrastructure owner-operators, such as Caltrans. He noted that improving safety was one of the most important benefits, along with enhancing accessibility for all user groups. Improving transportation systems efficiencies for trucks, personal vehicles, and transit for the movement of people and goods was another benefit he cited.

Dougherty provided an overview of the AV testing regulations that are in effect in the state and the AV operation regulations that are going through the formal rule-making process by the California Department of Motor Vehicles (DMV). He noted that regulations on the testing of AVs became effective in September 16, 2014. Currently, 36 companies are permitted to test AVs on California public roads. That number continues to grow. He reported that these companies fall into three general categories: conventional automakers and Tier 1 suppliers; technology companies; and start-up companies. Dougherty noted that the formal proposed rules on operating AVs and some changes to the testing regulations were published on March 10, 2017.

According to Dougherty, California is home to two of the 10 National AV Proving Grounds that were announced by the U.S. DOT earlier in 2017. The GoMentum Station on the former Concord Naval Weapons Station, operated by the Contra Costa Transportation Authority, is one of the proving grounds. The San Diego Association of Governments, Caltrans District 11, and the City of Chula Vista operate the second proving grounds on I-15, State Route (SR) 125, and the streets of Chula Vista.

Dougherty presented videos highlighting Caltrans-sponsored AV research on passenger cars, commercial trucks, transit buses, and snowplows. He noted that Caltrans has a long and rich history of leadership in research, dating back to the early 1990s. He discussed the ongoing partnership with the California Partners for Advanced Transportation Technology (PATH) Program at University of California (UC), Berkeley, on many projects. Caltrans and PATH were core members of the National Automated Highway System Consortium, a \$200-million federal program led by General Motors that ran from 1994 to 1998.

The culmination of this effort was called Demo '97, which was conducted in August 1997 on the I-15 barrier separated high-occupancy vehicle (HOV) lanes in San Diego. The 4-day

event attracted almost 4,000 transportation experts from around the world, and gave them an opportunity to experience automated driving first-hand. A video highlighted the eight-car automated platoon of Buick LeSabres developed by researchers at General Motors and PATH.

Dougherty described a video showing cooperative adaptive cruise control (CACC) undertaken by Caltrans and PATH, in partnership with Nissan. He noted that with CACC, the four vehicles use dedicated short-range communication (DSRC) to communicate vehicle-to-vehicle (V2V), so when the lead car brakes, the following cars know instantaneously, and brake almost immediately, complementing their own onboard sensors. Dougherty suggested that if CACC technologies were widely deployed, it would enable vehicles to safely follow at reduced distances, which would potentially increase the vehicle-carrying capacity of existing roadways.

The next video illustrated commercial truck automation. A three-truck platoon was tested on Nevada SR-722 in 2010. Since the annual average daily traffic for this route was 50 vehicles, the Nevada DOT allowed Caltrans to close the road for short periods of time to perform the test. DSRC was used to share dynamic data between the trucks, enabling them to safely follow at distances of approximately 25 ft. He noted that some of the benefits of this technology are significant reductions in fuel consumption and associated emissions for all three trucks due to the drafting effects of close following.

Dougherty also showed video of the recent three-truck platoon demonstration conducted on I-110 near the Port of Los Angeles in March 2017. The demonstration is part of an FHWA-sponsored Exploratory Advanced Research Project on partial truck automation. The drivers are still steering the trucks, but the brakes and throttle are controlled by a computer, based on inputs from onboard sensors and V2V data shared between the trucks. The spacing between trucks for this demonstration was 50 ft. He noted that the efficient movement of trucks is important for the ports of Los Angeles and Long Beach, the largest port complex in North America. The demonstration provided port executives with an opportunity to see the potential application and benefits of truck platooning.

Dougherty reported that in 2003, Caltrans and PATH, in conjunction with the Federal Transit Administration (FTA), hosted a national conference on bus automation, using the same I-15 test facility that had hosted Demo '97. He presented a video showing a two-bus platoon from the conference. A three-bus platoon and precision docking was also tested. He noted that this technology was perceived to enable a "rubber-tired" light rail system at a fraction of the cost of conventional light rail and with greater flexibility.

Dougherty reported that the success of Demo 2003 led to Caltrans and PATH receiving a grant from the FTA in 2009 to develop bus steering automation under the Vehicle Assist and Automation Program. Caltrans partnered with the Lane County Transit District of Eugene, Oregon, which operates a bus rapid transit (BRT) system through the campus of the University of Oregon. The same steering automation system developed for Demo 2003 was used to automate the bus steering for this project, while the drivers still controlled the brakes and throttle. He noted that there is an effort underway to commercialize the technology to make it available for other agencies.

The final video highlighted a snowplow research project, which was undertaken in partnership with UC Davis, the Minnesota DOT, and the University of Minnesota. The project uses many technologies similar to those employed by AVs. Based on a high-precision digital map with high-accuracy differential GPS, snowplow operators are shown an "augmented reality" on the heads-up display in their line-of-sight, which enables them to "see" the roadway even during low-visibility, such as white-out conditions.

In closing, Dougherty noted that Caltrans AV research covers the broad spectrum of vehicle types and applications. He stressed that these applications focus on Caltrans' mission, which is to provide a safe, sustainable, integrated, and efficient transportation system to enhance California's economy and livability. He recognized the expertise of symposium participants and challenged participants to help turn the promise of AV technologies into a reality that provides transformational benefits to society.

New Ventures *Opening Keynote Address*

GILL PRATT
Toyota Research Institute

Gill Pratt began by asking how hard could autonomous driving be. He noted that there were three basic rules for an AV: stay on the road, do not hit anything, and do not get hit. He suggested that it was difficult for technology to do all those things and to meet the high standards necessary for daily operation on the roadway system.

Pratt commented that due to the combined efforts of all levels of government, automobile manufacturers, and other groups, human-driven vehicles are remarkably safe. He said that the hope is to, someday, reduce traffic fatalities to zero, but that the figure in the United States of approximately one fatality per 100 million miles traveled indicates the overall safety of the roadway system.

At the same time, Pratt suggested that social tolerance of machine-caused crashes is low. He questioned if society would accept only one fewer fatality with a fully automated vehicle fleet or if the expectation is that AVs will need to be much safer than human driving for public acceptance. He asked how much safer than human driving is safe enough for AVs. He suggested that answering this question was up to society, not industry or researchers. He stressed the importance of discussing this question with the public and with policy makers.

Pratt described the Toyota Research Institute (TRI) and its role in addressing these questions. He noted that TRI was established in January 2016 with an initial budget of \$1 billion. As of July 2017, TRI had 200 employees.

Pratt discussed a continuous improvement process called “Kaizen,” which is a Japanese word meaning “improvement.” He provided an example of using Kaizen to examine vehicle design and vehicle fitness. The concept is to improve overtime through small increments, reaching the top of a bell curve. He noted that Toyota, and many other automotive companies are good at using this approach. As factors such as increasing fuel prices, influence consumer preferences on car size, however, the optimum vehicle design is no longer optimum and adaptation and change is needed. He noted that businesses can adapt if the environment changes slowly, but that it is difficult for businesses to adapt when there is a paradigm shift or when a new market emerges.

Pratt cited autonomy and mobility as a service (MaaS) as examples of paradigm shifts and new markets. He noted that these types of events create prediction uncertainty. In these situations, businesses are uncertain of the best course of action due to many unknowns. He suggested that in these situations the best approach is simply to try, even when multiple failures may be the result. When you try enough times, however, success often emerges. He said that TRI was established to try by conducting high-risk, high-reward research.

Pratt provided an analogy to comic book action heroes to describe TRI’s original approach. He suggested that OEM’s are strong like the Thing (trademark Marvel Comics), while TRI is agile like the Flash (trademark DC Comics). He noted that combining them, which Toyota and TRI are doing, results in Superman (trademark DC comics), who is both incredibly strong and incredibly agile.

Pratt asked the rhetorical question: Can Toyota and TRI do this alone? Given that the AV space is the most competitive technology market today and that the number of start-up companies is accelerating, he said that the answer is no—Toyota and TRI cannot do it alone. Continuing the superhero analogy, Pratt said that TRI’s new approach is to combine strength of the Thing with the agility of the Flash and all his friends, such as those dressing up as their favorite action heroes at Comic-Con, to create a stronger and more agile team.

Pratt announced the new Toyota Artificial Intelligence (AI) Ventures, which is a corporate venture capital fund of \$100 million initially. He described the three goals of Toyota AI Ventures, which include providing access to scarce talent and disruptive technologies, experimenting with new business models, and examining financial returns. He noted that activities will include early-stage investments and cultivation of new business. Pratt highlighted the focus areas for Toyota AI Ventures, including AI, data and the cloud, robotics, and AV mobility. He reported that Jim Adler, who was previously TRI Vice President of Data and Business Development, is now the Managing Director of Toyota AI Ventures.

Pratt described the overall venture fund structure. Toyota AI Venture is a subsidiary of TRI. Funding will be used to invest in start-ups and to cultivate start-ups and beta test new business models. He noted the differences from traditional venture capital funds. First, Toyota provides resources, but is also a customer for start-ups. While start-ups will be able to serve other customers, having Toyota as a stable customer is viewed as a major benefit. Second, the “pitch and decide” approach is typical with entrepreneurs and venture capitalists—the entrepreneur makes a pitch and the venture capitalist decides if they want the product or service. In addition to using this approach, Pratt said the Toyota AI Ventures will more often use a “call and response” approach, which will include making requests for assistance on specific topics and issues. The responses will be evaluated and a few investments will be made to the best proposals.

Pratt described three investments Toyota has made recently to provide examples of the focus of Toyota AI Ventures. One example was a tech start-up called Nauto that uses AI cloud telematics to improve driver behavior. A second example was SLAMCORE, which provides low-power localization, mapping, and computer vision. A third example was intuition robotics, which is developing an active aging companion for older adults. These examples were highlighted in a video.

Integrating Autonomous Driving into the New Automotive Reality

MAARTEN SIERHUIS

Nissan Research Center, Silicon Valley

Maarten Sierhuis described Nissan's road map for autonomous drive technology development and Nissan's approach for socially acceptable autonomy. He noted that the roadmap is based on geographic areas where the technology would be used, rather than the SAE levels of autonomy. The roadmap envisions Nissan's autonomous vehicle technology, which is Hands-Free but Eyes On, meaning that the driver is still in control and responsible for observing and monitoring the system in operation through 2020. He commented that these Eyes On technologies were primarily Level 2. He reported that the deployment of these technologies will expand from a single-lane highway application to multiple highway lanes to urban intersections. The Eyes Off technology for a fully autonomous driverless Level 4 or Level 5 vehicle will occur sometime after 2020. He noted that this level will allow for the creation of Autonomous Mobility Services.

Sierhuis reviewed his comments at the 2016 AVS on "Socially Acceptable Autonomy" related to the need for AVs to behave in a socially-acceptable manner with other users, and the need to be seen as being in an interdependent relationship with people. He suggested that this interdependence is a major shift in what it means to "drive" a vehicle. He noted that one of Nissan's research focus areas is developing technology to best manage that interaction. He suggested that it is viewing interaction more as teamwork between the driver and the car, where the driver becomes more and more a passenger, and the car does the driving.

He continued the discussion of this interdependent relationship, but focused on self-driving or driverless vehicles when there is not a human driver in the vehicle. He noted that a major challenge in moving forward toward a socially acceptable driverless vehicle is making sure that driverless vehicles can seamlessly cope with unexpected situations in very busy urban environments.

Two examples of real-life situations in urban settings that AVs will need to be able to cope with were described. The first example was an intersection in the Mission District in San Francisco. A truck repairing overhead wires was blocking the single traffic lane and no one was directing traffic. After considering the situation, he reported that the only thing to do was to cross the double yellow lines and drive on the other side of the street after the light turned green, knowing that other cars would be coming toward the vehicle. He commented that it would take a couple of minutes to decide what to do and then to negotiate the situation and asked if a self-driving vehicle would be able to do this by itself.

The second example was a more-complex situation in Palo Alto involving road repair at an intersection. He noted that he had to break two rules in this case—driving on the wrong side of the road and driving through a red light. He reported that in this case there was a person directing traffic, but questioned if a self-driving vehicle would know how to respond.

Sierhuis questioned if autonomous software technology will be intelligent and robust enough to negotiate all of the possible complex situations it may encounter. He suggested that seamless autonomous mobility (SAM), developed from National Aeronautics and Space Administration (NASA) technology, could serve as an important step in that direction, and could speed up the integration of AVs.

He suggested that learning from aviation, which has been managing crowded airspace for decades, may provide inspiration in addressing these issues. Sierhuis described the Air Route Traffic Control Centers and the role of air traffic controllers to illustrate this point. He noted that air traffic controllers are responsible for the safe, orderly, and expeditious flow of air traffic in the global air traffic control system. Usually stationed in air traffic control centers and control towers on the ground, they monitor the position, speed, and altitude of aircraft in their assigned airspace visually and by radar, and give directions to the pilots by radio. He reported that the position of the air traffic controller is one that requires highly specialized knowledge, skills, and abilities.

The SAM concept to address edge cases that need human perception, understanding, and decision was presented. He suggested that no fully autonomous system works without human-in-the-loop and that human-robot teaming brings the best of the two intelligences. He further suggested that a human safety net is expected by users. By including a human in the loop, the SAM concept enhances the autonomous capabilities of an AV fleet. Further, AI in the cloud assists operators and AVs to perform more efficiently.

Sierhuis described the Mobility Control Center that would be in operation with SAM. Mobility managers in the center would be responsible for the safe, orderly, and expeditious flow of autonomous fleets in the global system. He also noted that the system would use a form of distributed AI with a human-in-the-loop. Rather than individual intelligent autonomous agents driving around by themselves, a holistic multiagent system where AVs not only communicate with each other, but are also supported by AI in the cloud would be used. In the case of AI in the cloud where the vehicles cannot solve the problem, there would be a human observer, a so-called mobility manager, to help solve the problem with human intelligence. Thus, the Nissan SAM approach focused on a holistic multiagent system with human intelligence playing a key role. The SAM Fleet Management and VR (virtual reality) Teleoperation would use vehicle data stored in the cloud and 4G mobile communication with vehicles. He also highlighted functions of the SAM fleet supervision, SAM vehicle supervision, and SAM AV.

Global Scalability of Autonomous Vehicles

KARL IAGNEMMA

nuTonomy

Karl Iagnemma discussed the global scalability of AVs, including how to transfer autonomous technology developed for one city to other cities throughout the world. He noted that it was important to consider global deployment now, as it will influence development approaches and strategies.

Iagnemma reviewed the history of nuTonomy, which was formed in the summer of 2013 as a spinoff from the Massachusetts Institute of Technology (MIT). The company worked with Jaguar and Land Rover in 2014 and established their headquarters and operations in Singapore in 2015. In 2016, nuTonomy established a relationship with Grab in Singapore. He noted that entering the Boston, Massachusetts, market in 2017 highlighted the need to consider scalability and the ability to adapt software to different geographies. He also noted the 2017 partnership with PSA and Lyft in Boston and the anticipated 2018 expansion in Singapore.

Iagnemma discussed a possible timeline for the deployment of AVs. He suggested the need to consider two different use cases when considering deployment. One use case focuses on privately owned AVs and the second use case focuses on fleets of shared AVs to move people and parcels in major cities worldwide. He noted most OEMs are targeting the mid-2020s for Level 5 AVs for structured environments such as highways. He further noted that the slow pace of adoption reflects the rate of new car purchases and OEMs introducing advanced driving features in top-of-the-line vehicles first.

The second use case builds on pilots underway in Singapore; Boston, Massachusetts; Pittsburg, Pennsylvania; Phoenix, Arizona; and other major cities. He noted that nuTonomy expects the deployment of this use case to be faster than the private vehicle use case. He suggested autonomous fleets may account for as much as 25% of vehicle miles traveled (VMT) in the United States by 2030, with major market penetration by the 2040s. He further suggested that the second use case would result in major safety benefits, including reductions in fatalities, by midcentury.

Iagnemma presented a video highlighting nuTonomy activities in Singapore. He described the current capabilities of AVs within a geofenced area, which includes a vehicle traveling to selected destinations and navigating controlled and uncontrolled intersections, work zones, pedestrian crossings, and other environments. He reported that these operations can be made most, but not all, of the time. He suggested that not yet being at 100% reliability reflects the current overall status of pilots and deployment efforts.

Iagnemma described three phases of Level 4 and Level 5 vehicle penetration—proof-of-concept, validation, and scaling. He noted that the first proof-of-concept phase has been completed. He suggested that the industry is currently in a prevalidation phase. He noted that the validation phase includes extensive simulation and on-road driving to prove that the technology is safe by some standard, which has not yet been determined. He suggested that the validation phase will last most of the next decade. The third phase is scaling, which will occur after the technology has been validated for one city.

Iagnemma discussed elements that need to be considered in the scaling phase, using the example of transferring nuTonomy technology from Singapore to Boston. He noted the

differences and similarities between the two cities. The climates are different: Singapore is hot, humid, and rainy, while Boston can be cold and snowy. The roads are different: Singapore roads are well maintained, while Boston has potholes and other deteriorated conditions. The signs are different in the two cities, as is the side of the road people drive on. He reported that scalability requires adaptation and validation of AV software to those different conditions.

Iagnemma highlighted examples of the adaptation process in a new geography. Mapping the new city is a key first task. Perception and training the system on new signing and markings, as well as unique atmospheric conditions, road users, and infrastructure is a second task. Third, the software needs to reflect the planning and decision making in the new city, including driving rules and driving customs. Fourth, operational differences, including enforcement practices and other elements, must be addressed. Finally, integration with customer-facing networks must be established.

Iagnemma also described elements of the validation process focusing on simulation and on-road driving. One question is if validation in one city can be re-used to assist with validation in the next city or if the validation process has to start over from the beginning?

Iagnemma described the rulebook approach being used at nuTonomy as a step toward rapid scalability of AVs. He noted that a rulebook is a description of a law or preference, which is precise enough to be converted into a formal specification, which can then be automatically converted into software. He said that this approach enables rapid adaptation to environments with new driving rules and preferences, and enables the generation of verified code to streamline the validation process. He noted that this approach provides a path toward a scalable architecture for a rules-based AV system.

Iagnemma concluded by raising the following for open questions about scalability.

- How much simulation and driving is required for validation in an initial geography?
In a follow-on geography?
- How should similarities between regions be assessed so that the development and validation effort can be reduced?
- What fidelity of simulation is required, and how does this requirement influence how simulation can be employed?
- Are the answers to these questions distinct for rules-based or learned decision-making systems?

Regulating Autonomous Vehicles Amid Uncertainty

NIDHI KALRA
RAND Corporation

Nidhi Kalra discussed the risk and uncertainty associated with regulating AVs. She noted that RAND is a nonpartisan, nonprofit research institution conducting research to improve public policy. She said that in the interest of full disclosure, that her spouse is the cofounder of a machine learning (ML) and robotics startup engaged in AV development, but that his work has no bearing on her research.

Kalra reviewed three questions that formed the basis for her presentation. The first question was how safe should AVs be? The second question was how can we know how safe they are? The third question was how do we develop good AV policy, particularly given the answers to the first two questions?

In addressing the first question on how safe should AVs be, Kalra drew on the utilitarian argument that AVs should be allowed as soon as they are safer than the average human driver. She noted that while people tolerate mistakes from other people, they are far less forgiving when machines make mistakes. As a result, she noted that some people feel that until AVs are nearly perfect, they should not be allowed on roads. Kalra suggested that while research can inform this discussion, there is no correct answer due to differences in values and culture. Thus, she said that the answer to how safe on AV needs to be is uncertain.

Kalra examined the second question on how to know how safe AVs are. She stated that the recent RAND report, *Driving to Safety*, showed that test driving cannot be used as a means of proving that AVs are safe, because such proof requires hundreds of millions, if not billions of miles of driving. She noted that there is interest in developing modeling and simulation methods, test courses, and other means to assess the safety of AVs. These approaches have not been developed and validated yet. As a result, she commented that the answer to the second question is also uncertain.

Kalra noted that these answers pose a challenge to developing good AV policy, which is the third question. She examined this question in the context of the Federal Motor Vehicle Safety Standards (FMVSS), which pose a barrier to deploying some types of AVs. She reported that the FMVSS specify the design, construction, performance, and durability requirements for motor vehicles. She commented that these specifications get in the way of innovative AV designs.

Kalra suggested that the good news is that there is an existing exemption process that provides a path around the FMVSS to facilitate innovation. She noted that developers can apply to NHTSA for exemptions based on several concepts, including innovative safety features, which are the focus of many AV applications.

Kalra noted that the NHTSA limits the exposure to risk in two ways when granting exemptions. First, a developer needs to demonstrate equivalent safety. For example, if an automaker is seeking an exemption for a new rearview mirror design using a camera, they would have to document at least the same level of visibility as a regular rear view mirror. Second, the vehicle developer is limited to selling 2,500 nonconfirming vehicles per exemption per year.

In comparison, Kalra reported that in 2016 more than 17.5 million new cars and trucks were sold in the United States, and the most popular car models had sales of nearly 400,000 vehicles. She noted that the 2,500 vehicles allowed through the NHTSA exemption is a small number.

Kalra reported that as of June 2017, 16 AV bills had been introduced in the U.S. House of Representatives. The Practical Autonomous Vehicle Exemptions Act proposes raising the NHTSA exemptions limit from 2,500 vehicles per exemption per year to 100,000 vehicles per exemption per year as a way to lower the barriers of deploying AVs.

Kalra discussed potential advantages and disadvantages of increasing the exemption vehicle limit. She suggested that neither the letter nor the spirit of the exemption process works very well when it is applied to AVs. She noted that the letter of the law essentially requires automakers to demonstrate that the nonconforming vehicle can be driven as safely as a conforming vehicles. She further noted that the law assumes there is a human driver. With an AV, the automaker will need to demonstrate that the vehicle can drive itself safely.

As noted previously, if one wants to replace a rearview mirror with a camera, one has to show that the camera provides the same field of view to the perception software that the mirror provided to the human driver. She suggested that his approach ignores the real question: how well does the vehicle perceive its environment? However, there is no analogue in the FMVSS to the design and performance of perception software, since perception is a human function governed by state regulations administered by the DMV when you take a vision test. She noted that the FMVSS has nothing to say about the vision in an AV. For this reason, an exemption is not even required for an AV that conforms to the FMVSS, even if it is programmed to drive into the nearest wall.

Kalra suggested that one issue is that there is no definition of AV safety. Further, she noted that there is no practical method to demonstrate the safety of AVs prior to deployment.

Kalra returned to the third question on how to develop a good AV policy and selecting appropriate performance measures, thresholds, and number of vehicles. She suggested that this can be accomplished by recognizing and managing uncertainty.

Kalra discussed that regardless of topic, there is usually a trade-off between risk and uncertainty. She noted that the more precisely one wants to know how safe a disruptive, hard-to-predict technology is, the more risk one has to accept in deploying it to find out. She described the analysis conducted by RAND in the *Driving to Safety* report, which expressed this relationship mathematically. She noted that there is a trade-off in the miles of driving needed to prove AV safety. This trade-off is that for the smaller the difference, the more miles are needed to prove safety, and the rarer the event (e.g., fatalities), the more miles are needed to prove safety.

According to Kalra, this analysis means that a lot of risk would have to be accepted to detect even modest improvements in AV fatality rates over human driver fatality rates. She said that a 20% improvement would require 5 billion miles of driving. She suggested that this relationship could be used to bound risk while gradually increasing knowledge.

Kalra described the current exemption process as a single gate. She suggested that rethinking this approach to use a series of performance-based gates would be beneficial. At each gate, more AVs are allowed to be deployed, providing that they demonstrate meeting some safety standard. At the same time, she noted that the safety standard could become more and more comprehensive at each successive gate.

Kalra discussed that the numbers of AVs allowed by an exemption and the safety standard can be based on the risk/uncertainty trade-off. She described an example of initially allowing 5,000 vehicles per exemption per year. At the average annual 12,000 mi people drive, the exempt vehicles would collectively drive 60 million miles in a single year, which is enough to determine in the first year if the AV fleet is at least 10% safer than human drivers in terms of crashes, or at least 15% safer in terms of injuries. She said that we would not know about

whether the AVs are better or worse in terms of fatalities unless the performance difference were very large—at least 80% better or 80% worse. She said that this might be the uncertainty we accept in order to bound our risk. She suggested that this could be the basis of the design of one of the performance gates.

Kalra continued the example by allowing 20,000 AVs to be deployed per exemption per year. At 12,000 annual miles per AV, this would provide a total of 240,000 mi for analysis. She noted that this level would allow detecting essentially any difference in crashes and injuries. It can also detect differences in fatality rates of 55% or more. She suggested that this level of risk could be a first gate to allow for more learning, or it might be the basis of the second gate, once the first gate has been reached.

Kalra summarized the following three key points from her presentation. First, she suggested that when faced with great uncertainty, it is almost impossible to get regulations right the first time. Second, she noted that policies that manage uncertainty could enable innovation, while balancing the tradeoff between risk and reduction of uncertainty. Third, she suggested that a graduated approach additionally helps avoid the problem of trying to shut the barn door after the horse has bolted, because there are several well-designed doors.

Automated Vehicles and Regulation *Panel Discussion*

STEVEN SHLADOVER

PATH, University of California, Berkeley, moderator

JOHN BOZZELLA

Association of Global Automakers, panelist

JAMES FACKLER

Customer Services Administration, Michigan Department of State, panelist

JOHN SIMPSON

Consumer Watchdog, panelist

ALICIA FOWLER

California State Transportation Agency, panelist

Steven Shladover initiated the panel discussion by reviewing the September 2016 NHTSA Guidance. He noted that the major elements in the document included vehicle performance guidance, a 15-point checklist for safety assessment primarily for highly automated vehicles (HAVs), and a model state policy. It outlined some of the boundaries between federal and state roles, reviewed the current federal regulatory tools, and suggested potential new federal regulatory tools. Panel members made brief introductory comments and Shladover asked the panelists a series of questions focusing on regulations relating to automated, connected, and AVs.

Alicia Fowler described the regulatory responsibilities of the California DMV associated with AVs operating on public roads in the state. She noted that safety is a major focus of the department's oversight of AVs. She agreed with other symposium speakers that it is a complicated area to regulate.

Fowler reported that the California DMV issued regulations on testing AVs on public roads in 2014. She noted that 36 companies have been approved and are testing AVs in the state. She said the testing safety record was encouraging, with no major incidents. She also reported that having test vehicles on California's roads is providing data to better understand and validate the safety aspects of AVs. She stressed the importance of vehicles operating safely around schools, pedestrians, bicyclists, as well as law enforcement, fire, and emergency medical services vehicles.

Fowler reported that new state regulations addressing driverless vehicle testing and deployment have been developed and are in the active regulatory promulgation process. Safety is also a major component of these regulations. She noted that the development of these regulations is a very public process, with input from numerous groups. Fowler also described the Law Enforcement Interaction Plan, which requires manufacturers to provide guidance to law enforcement when they need to interact with AVs, and the Consumer Education Plan, which provides information about AVs to end users.

Fowler described the interest in balancing regulations with encouraging innovation in AV development and deployment in the state. She noted that the 36 companies currently authorized

to test in California include OEMs and start-up companies. She highlighted the proving grounds in the San Diego area and at GoMentum Station in the San Francisco Bay Area.

James Fackler described the history of the automotive industry in Michigan. He noted that regulations in the state focus on allowing the industry to build and test products on public roads that will eventually be commercialized.

John Bozella introduced the Association of Global Automakers, which represents OEMs, as well as Tier 1 suppliers, technology companies, and other businesses who make up the AV ecosystem. He noted that these companies are investing billions of dollars to develop and deploy advanced technologies in personal and commercial vehicles. He commented that the broad membership provides for robust conversations at the intersection of innovation and policy.

Citing the recent increases in fatalities from motor vehicle crashes, Bozella noted that improved safety is viewed as the major benefit from AVs. He suggested that a combined systems approach involving highway and roadway users, innovators, automotive companies, infrastructure owners, safety advocates, and other groups is needed to reach the Vision Zero goal of no fatalities. He further suggested the automated and connected vehicle technology provides the foundation for reaching this goal.

Bozella described the innovation occurring throughout the automotive and technology industries. He suggested that the opportunity exists to save lives at the same time regulators are developing the appropriate and necessary regulatory framework. He further suggested that one set of “running rules” is needed during this interim period. He noted that the federal government is the primary regulator of the automotive industry in the United States and stressed the importance of a uniformed national approach.

Bozella expressed the need to break down regulatory barriers and support innovation. He suggested that providing federal regulators with additional tools focusing on innovation would be beneficial. He noted that the safety assurance process included in the federal vehicle policy was an important tool. This process ensures that the conversations between the innovators and the regulators is always top of mind. He also stressed the need for flexibility. The current exemption process allows innovators to show that self-driving systems or other technology provide equivalent or better safety. He also noted the need to update the human-based elements of the FMVSS that still refers to hands, feet, and eyes.

Bozella commented that consumers and the market—not the government—should pick the technology and service winners and losers. Innovators should have the opportunity to develop products and services that customers want and that bring public benefits. He suggested that CAV technologies have numerous benefits beyond safety, including improving mobility for many individuals and enhancing the environment. He noted that new models for ridesharing, vehicle sharing, and vehicle ownership in partnership with automation would create more demand for electric vehicles (EVs). He stressed the need to support innovation, while ensuring public safety, to promote a robust industry and to realize the numerous benefits from CAVs in the United States.

John Simpson discussed the use of public roadways for the private testing of vehicles and the obligation to meet certain enforceable safety standards. Further, he said that there is an obligation for transparency on the part of companies to explain the tests being conducted.

Simpson reported that Consumer Watchdog supports the development and enactment of enforceable NHTSA standards that apply specifically to AVs. He said that the recent policy with the 15 self-check principles submitted on a voluntary basis was not adequate. He said that if federal agencies do not act, it is incumbent upon the states to enact safety regulations. He noted

that a patchwork situation of multiple state regulations would not exist if federal safety standards were enacted. He also suggested that there is a clear history of performance standards, not design standards, driving innovation.

Simpson applauded California for developing testing regulation with 36 companies approved to test in the state, he suggested the regulations must not be too onerous for the private sector. He noted that regulations support transparency by requiring companies to submit reports of any crashes within 10 days of the incident and annual reports of times when a vehicle disengages from self-driving mode and returns control to the driver. He noted that this information is of interest to policy makers and the public.

Panelists responded to questions from the moderator and the audience. The following points highlight topics discussed during this portion of the session.

- Panelists discussed the benefits of involving diverse stakeholders in developing regulations and guidelines. The suggested stakeholders included policy makers and agencies at the federal, state, regional, and local levels; the diverse private companies involved in developing and testing vehicles; interest groups; and the public. Panelists highlighted examples for different approaches and some noted that the model state polices provided a good base to begin discussions.

- Panelists discussed the desire for a regulatory approach that allows for innovation, while ensuring the safe operation of the roadway system. Panelists noted the challenges of developing regulation in a dynamic environment. Providing flexibility to respond to changing conditions was suggested as beneficial by some panelists.

- Providing a level playing field for all groups interested in testing AVs, as long as they meet the safety requirements, was discussed by panelists. The mix of groups involved in different partnerships, from OEMs to start-ups, was noted as a challenge by some panelists. Addressing vehicles operating at different SAE levels of technology was also noted as a challenge, as was dealing with the potential period when there will be a mix of legacy vehicles and AVs.

- Panelists discussed public acceptance of different AV technologies. They noted that regulations will need to consider early adopters, as well as technology laggards. Some panelists noted that regulations can help build public trust in technology.

- Panelists discussed some of the different ways states are working together on regulatory issues and coordinating approaches. Panelists noted the use of the model state policy and the assistance provided by various national organizations.

Automated Vehicle Regulations in Europe

EDWIN NAS

Connected and Automated Driving

Ministry of Infrastructure and the Environment, Netherlands

Edwin Nas discussed vehicle regulations in Europe, which are very different from those in the United States. For example, there is no FMVSS in Europe that will check vehicle conformity aftermarket launch. Rather, there is specific premarket type of approval process, which requires that a vehicle is title checked up front, which is more or less a check-box approach. New types and innovations can always be addressed, but with the rapid pace of technology development, he suggested the need for advanced flexibility to support innovation.

Nas explained that the Netherlands served as the President of the European Union (EU) in 2016. He noted that the Netherlands has used the presidency to put connected and automated driving on the political European agenda. The Declaration of Amsterdam on Cooperation in the Field of Connected and Automated Driving was supported by all EU-member countries, car-industry and the EU. The Declaration provides a political statement and action agenda on accelerating the deployment of CAVs in Europe by 2019.

Nas described the vision in the EU focusing on combining information on traffic and vehicle automation. He noted that the Netherlands has a long history and robust intelligent transportation system (ITS), which is being connected to and matched with information from vehicle automation.

Nas reported that the follow-up to the Declaration of Amsterdam was an action agenda for governments and the automotive industry, including structural high-level meetings twice a year in different countries. The meeting in February 2017 was held in Amsterdam and the September 2017 meeting was conducted in Germany. He suggested that there are numerous benefits from sharing the experiences from the EU with others in the United States and throughout the world. For example, Nas described the ethical principles associated with automated driving developed by the German Ethical Commission which provides answers that are useful for everybody. He also noted that V2V communication will be discussed at the following meetings.

Nas commented that two worlds—one involving the existing transportation system and one involving AVs—are moving toward each other. He described the need for a robust system to address all the different traffic situations automated and AVs will encounter.

Nas suggested that with the rapid changes in software and vehicle technology, more than just a certificate of compliance is needed. He proposed a new approach involving performance-based standards and acceptable means of compliance. He learned from the aviation industry a possible model for this functional rule-based approach. Aviation has one rule: you have to fly safely. The other items are the acceptable means of compliance. He suggested that regulations should describe the what, not the how. Innovations that are proven to be safe can be added to the acceptable means of compliance.

Nas described a possible transition scheme to the new approach, highlighting the importance of the change in responsibility from the driver to the vehicle. He noted that the SAE levels are beneficial in explaining the changes in technology, but that the role and responsibility of the driver in different use cases needs to be described more extensively. The role of the driver

may not be the leftover part of technological advancement. He further suggested that a matrix with driver levels of responsibility was needed.

Nas stated that the Netherlands is very ambitious and already testing CAVs of all types of automation and connectivity on the open road nationwide. He further discussed that the Netherlands favors a two-phased approach to legislating AVs. Elements in the first phase would focus on opening the door, creating the possibilities for development by allowing AVs, defining legal barriers for market introduction, and addressing potential societal implications. The second phase would focus on legislating the right requirements based on the experiences from testing and experiments, developing a better understanding of what to regulate, and optimizing the choice for functional or technical requirements and standards. The learning by doing strategy works perfectly in this approach.

Nas discussed the importance of the current global framework for both the United States and the EU and national frameworks. He noted that the United Nations Economic Commission for Europe is focusing on supporting connected and automated driving by addressing the role of the driver as related to new vehicle systems. Here also the legislative boundaries for the United States are layered down. He highlighted the following new draft guidance on driver distraction.

When the vehicle is driven by vehicle systems that do not require the driver to perform the driving task, the driver can engage in activities other than driving as long as

- Principle 1: These activities do not prevent the driver from responding to demands from the vehicle systems for taking over the driving task.
- Principle 2: These activities are consistent with the prescribed use of the vehicle systems and their defined functions.

He noted that new guidance is being developed for HAV and driverless vehicles that addresses both the Geneva and Vienna Conventions. He noted that the Geneva Convention (which also binds the United States) cannot be changed, but that the Vienna Convention can be updated and modernized. We are striving for a worldwide solution that will benefit all countries for all conventions.

Nas described the GEAR 2030 EU program, which includes a high-level group composed of representatives from industry, nongovernmental organizations, and member states. He reviewed the objective of GEAR 2030, which is to build a coherent approach on the industrial development of CAVs. Being the rapporteur to the EU for Connected and Automated Vehicles, he highlighted this dedicated working group on CAV with car manufacturers, suppliers, member states, the insurance industry, telecom providers, and nongovernmental organizations. The working group is focusing on policy, regulatory, and financing issues.

Nas noted that the EU framework already provides a relevant framework for automated and connected cars expected to be on the market through 2020. Long-term recommendations for vehicles expected to be available through 2030 is anticipated by September 2017. He noted that the approach introduced voluntary building blocks for cross border testing, which are being shared with other countries to enhance learning from international testing.

Nas highlighted upcoming technology systems that should be available by 2020 using SAE level 2, 3, and 4. Examples cited included highway pilot and truck platooning, traffic jam assists and maneuvers at low speed, and dedicated POD [or personal rapid transit (PRT)] vehicles in separate areas and on the open road. He also noted that border crossing traffic will be tested for interoperability and multinational cooperation.

Nas described some of the elements of the approach being taken in the Netherlands. He noted that all open-road testing with a driver present has been possible nationwide since 2015. He further noted that the Netherlands has a one-stop shop for exemptions, that having a driver inside or outside a vehicle is within the law, that there is no legal reference to holding the steering wheel, and that distance keeping is based on the functional rule of “keep a safe distance.” He described a new nationwide experimental law, which should go into effect in 2018. This law will allow driving on the open road without a driver inside the vehicle, which will also provide a new approach for the term “driver,” and will allow for new testing possibilities for HAVs and fully automated vehicles with or without drivers on board. Other projects he highlighted included the Daimler automated bus, simulations, closed- and open-testing environments, and the Smart Mobility Embassy. This to state that the Netherlands will match their ambition with nationwide initiatives on the road and is ready to host tests and experiments for all who want to make connected and automated driving a reality.

Deep Learning and Highly Automated Vehicles

ROBERT SEIDL
Motus Ventures

Robert Seidl discussed deep learning, which is a subset of AI, and AVs. He noted that the interest in deep learning has exploded in the past 5 years. He suggested that this interest and the use of deep learning was due to the wealth of available data and the ability of computers to analyze large amounts of data. According to Seidl, both of these conditions are needed for deep learning. He noted there are success stories of applying image recognition in medicine and other fields.

Seidl described applications of deep learning with AVs. He noted that object recognition, detection, and classification are big tasks with AVs. He also discussed the use of image segmentation and free-space detection with AVs.

Seidl described how deep learning works. He noted that deep learning networks consist of artificial neurons, which are structured in different types of layers and which have different functions. These layers include convolution, pooling, softmax, and other layers. Seidl noted that defining the different layers was still an open field of research.

Seidl reported that the networks need to be trained, which is a very laborious and data-intensive process that takes a lot of time and computing power. The training begins with labeling a set of data, such as a photograph of a Tesla. The forward pass continues to examine photographs. If it comes to a different model, such as an Audi, it makes a correction through a back error adjustment pass. This process is repeated over a million times.

Seidl discussed how deep learning is applied to AVs. He noted that to date, deep learning has been used heavily in sensing applications and a little in planning applications. He said that sensors generate a lot of data and that neural networks are good at working through data. He also highlighted an end-to-end application involving data from raw sensor inputs to steering and braking outputs.

Seidl discussed some of the challenges and opportunities of applying deep learning to AVs. One challenge he noted was that the traditional engineering “V” model, which includes decomposition and testing as you move up it the “V,” does not work well with deep learning, as the functional and safety requirements can only be tested at the top level. He noted that current coding tools and methods are well developed around procedural coding. He reported that the same level of practice has not yet been reached with neural networks and deep learning. He also noted that the exact network architecture is still in the development phase.

Seidl also discussed the rules and procedures that do not need to be learned by using 100,000 examples. He noted that people do not teach their children not to run into the street by letting them do it 60 times. He suggested that the same is true with deep learning—vehicles stop at a stop sign. He said that researchers are still working connecting the data obtained from simulations and road tests.

According to Seidl, the life-cycle management of these systems is very complex. He noted that OEMs typically focus on robust and affordable solutions to one function at a time, such as automated emergency braking. With AVs, data from numerous sensors feed into a single computer. Anytime the orientation of a sensor changes or the contributing software changes, the whole system has to be re-valuated. He suggested that automobiles are becoming software,

which means that automobile development life-cycle costs are moving from development into maintenance, which is a big change.

Seidl highlighted opportunities associated with deep learning, including functional and safety validation using sensor simulation. He described the need to conduct simulation testing of different conditions—day, night, rain, fog, snow, and different lighting conditions—over thousands of cases. He suggested that simulation was a key driver for AV success. Simulation is controllable, repeatable, and scalable. It is also not dangerous, and it generates a lot of training data, which is needed for deep learning. Most importantly, he noted that simulation training is transferable to the real world.

Seidl discussed the importance of sensor fusion and maps with AVs. He also noted the importance of behavior recognition, not just object recognition. He highlighted the ability of pedestrians and drivers to make eye contact to help avoid crashes at intersections. He also stressed the importance of transparency in data sharing.

Systematic and Data-Driven Approaches to Autonomous Vehicle Testing and Certification

MICHAEL WAGNER
Edge Case Research

Michael Wagner discussed the need to develop guidelines related to building safer autonomy. He focused on tools and techniques to build safety at the lower level, rather than the policy levels addressed by other speakers. He noted that Edge Case Research provides verification capabilities for manufacturers of autonomous systems. He also reviewed his extensive experience in developing autonomous systems.

Wagner discussed that safe software is developed according to the “V” process model and different industry standards. He noted the key element of the V process is traceability. The process identifies the potential risks. Safety specifications are developed to mitigate the risks. The system, which has been developed according to industry best-practices, satisfies the safety specifications.

Wagner discussed the difficulties with autonomy. He noted that the intent is to develop autonomy that will be safe in all unspecified environments. There is not a complete specification for the operation domain, however. As a result, he said that it is not possible to develop a complete set of requirements that captures and defines all the potential behaviors. Wagner noted that defining operational design domains (ODDs) that constrain the situations in which autonomy must behave safely is the typical response. He reported that the problem is that two domains that seem equivalent to humans may not seem to be equivalent to autonomy.

Wagner described results from deep learning in research, highlighting that the impact of small changes can be surprising. He also described the challenge of detecting and object and responding to it properly. He noted that there are rarely explicit definitions of the objects AVs need to respond to, such as defining a pedestrian. He noted that using ML is possible, but that traceability is lost.

Wagner described approaches for addressing these challenges. He noted that simplex architecture provides a system design that makes it easier to verify safety claims. He further noted that the simplex architecture pattern has been used in the aerospace industry and DARPA’s High-Assurance Cyber Military Systems program. A simple, verified Safety Controller can help mitigate risks in an unverified Complex Controller. The complexity is in the Decision Logic Module, which is responsible for swapping in the Safety Controller before an accident occurs, which can be extremely challenging. He said that the simplex approach is useful for supporting phased-deployment safety concepts, which involves ever-decreasing constraints on what the autonomy system can perform.

Wagner presented a more-advanced architectural pattern developed by his team at Carnegie Mellon University. The two-channel architecture segments autonomy architecture into checkable pipeline stages, and defines safety behaviors that are triggered when a primary-channel safety gate fails silently.

Wagner described some evolving safety concepts, including modeling the operational domains and the function architecture of the AV to generate a fault tree, which are causal models of how different events can lead to the actions that should be avoided. The fault tree is then used to identify risks and opportunities for mitigations. He noted that this process was currently very manually intensive, but that the ability to iterate different safety concepts may be possible with

more sophisticated technology. Wagner noted that the safety gates check previously verified impacts against currently unverified outputs. It is not possible to previously verify the inputs to perception.

Wagner discussed deep learning and the difference between explanation and verification. Verification is the independent determination as to whether the necessary causal relationships are in place. He presented examples of research trying to fool a deep learning system. In one example, the system identified that a baseball was white with red stitching, but missed that it was a sphere. A second example focused on the system developing the concept that a dumbbell was always held by human's arm, which means it would not recognize a dumbbell on the floor. He suggested that this unreliability might cause problems with detecting pedestrians. A system that has been trained that a pedestrian has two feet, would not detect a wheelchair user as a pedestrian. He pointed out that there are empirical ways of studying what a system has learned. Test generation techniques allow access to the network to understand what correlation might exist. He stressed the need to produce an independent verification of what the systems have learned.

Wagner suggested that lessons can be learned from other industries on how to verify a deep learning system where traceability does not exist. He noted that the pharmaceutical industry conducts numerous clinical trials on new drugs. He further noted that trials with autonomy can be simulated with numerous tests conducted in a relatively short time. He cautioned that the tests need to be conducted by the verifiers, which will require addressing data sharing and intellectual property issues. He stressed the need to build best practices. He also stressed the need to bring together groups from traditional traffic safety, artificial intelligence and deep learning, and automotive and physical safety to help develop actionable best practices.

PEGASUS

First Steps for Safe Introduction of Automated Driving

HERMANN WINNER
Technische Universität Darmstadt

Hermann Winner discussed the status of PEGASUS, which is the 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. He noted that PEGASUS is a 42-month project (January 2016 to June 2019). It includes the five German OEMs—Audi, BMW, Daimler, Opel, and Volkswagen—as well as Tier 1 suppliers, test laboratories, scientific institutes, subject matter experts, and subcontractors.

Winner described the central issues of the PEGASUS project. He identified two of the key questions examined in the project. What level of performance is expected of an AV? How can we verify that it achieves the desired performance consistently? He reviewed the four pillars of the project, which are scenario analysis and quality measures, the implementation process, testing, and reflecting on the results and imbedding them.

Winner discussed the scenario analysis and quality measures. The process begins with the description of the application scenario. He provided the example of the “highway chauffeur” and enhanced application scenario. The next step is the determination of critical traffic situations. The next step is the determination of the human and mechanical performance, as well as effectiveness. The next step is the determination of the safety level through an assessment of the probability of occurrence and mechanical manageability in critical situations. Additional steps are the deduction of an accepted quality measure for automated driving features and the deduction of requirements based on the accepted measure of quality.

The implementation process describes six elements. The first element focuses on an analysis of modification needs of existing metrics and the automobile series development processes. The second element addresses the transfer of systematic scenario guidelines into process steps in consideration of system classifications and levels of vehicle utilization. The third element is the transfer of target value parameters into the process steps. The fourth element is the preparation of requirement definitions for simulation, lab tests, and test grounds. The fifth element is refinement of the guidelines for required documentation of the process steps. The sixth element is the development of guidelines and protocols for the documentation of technological state-of-the-art compliance during the development process.

The following questions being examined in the testing phase were reviewed. 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?

Winner described the generation of scenarios for testing and the levels of abstraction. He noted that the scenarios include functional scenarios, logic scenarios, and concrete scenarios. The test preparation includes developing the database with the scenarios, and developing the test concepts. He noted that actual testing may include the use of simulations, test grounds, and field tests. Verification, calibration, and validation are important steps with all these methods.

Winner discussed the sustainability of the PEGASUS project results and the process of embedding the results. He discussed the verification of methods to identify relevant situations, as

well as quality and criticality measures for the assurance of highly automated driving features. He noted that an assessment can be made on whether a test goal can be achieved with the processes and methods in PEGASUS. He also noted that the use of different applied test methods—from simulation to test ground to field test—could be stated. The proof-of-concept process includes verification, assessment, and statement. Assistance with embedding the results with project partners can be documented. Finally, he noted that lessons learned regarding the implementation of the results in existing corporate structures can be provided.

Winner concluded by reviewing PEGASUS goals beyond research. He noted the PEGASUS is a national project promoting rapid progress in automated driving. He stressed that the embedding of findings in the industry was important. He also highlighted the distribution and pioneering of standardizations from the project. He reported that all essential project results are freely accessible. He also stressed that collaboration with other consortia is greatly appreciated and that a worldwide common understanding of how the safety of automated driving will be assured was needed.

In closing, Winner invited AVS participants to attend the PEGASUS Symposium called “How Safe is Safe Enough” on November 9, 2017, in Aachen, Germany, to share information with safety assurance experts worldwide. He noted that the symposium will include keynote presentations, panel discussions, and exhibitions focusing on PEGASUS and the major results of the first half of the project.

Let's Move the Security Needle *Think Offensively*

JONATHAN PETIT
OnBoard Security, Inc.

Jonathan Petit discussed the ongoing security concerns with AVs. He highlighted recent hacking examples and the need for research to address these concerns. He reviewed topics discussed at previous AVS general sessions and breakout sessions.

Rather than conducting a separate breakout session on cybersecurity this year, Petit invited symposium participants to think offensively about security during the breakout group discussions. He asked for participants to submit their comments, questions, and concerns to an e-mail address during the conference. A list of resources was made available for participants.

Welcome from the Transportation Research Board

NEIL PEDERSEN

*TRB, the National Academies of
Sciences, Engineering, and Medicine*

Neil Pedersen provided a welcome from TRB. He noted that TRB was pleased to cosponsor the symposium with AUVSI. Pedersen summarized the major roles of TRB and highlighted recent activities related to CAVs and transformational technologies.

Pedersen noted that TRB is part of the National Academies of Sciences, Engineering, and Medicine. The Academies is a private, nonprofit institution that provides independent, nonpartisan, objective, expert advice on scientific, engineering, and medical issues. Pedersen reported that TRB manages research, convenes experts, and provides independent, nonpartisan, objective advice.

Pedersen highlighted some of the transformational transportation technologies being explored in research projects, conferences, and other activities. These technologies included CAVs, shared-use services, the next generation air traffic control systems, unmanned aerial systems, smart cities, the Internet of things (IoT), big data, cybersecurity, alternative-fueled vehicles, and three-dimensional (3D) printing.

Pedersen reported that TRB administers over \$58 million annually in its cooperative research programs. The three programs—the National Cooperative Highway Research Program (NCHRP), the Transit Cooperative Research Program, and the Airport Cooperative Research Program—focus on practical research addressing issues faced by infrastructure owners and operators.

Pedersen described TRB CAV research projects. He noted that the NCHRP has invested \$5 million in connected vehicle (CV) and AV research since 2014. The results of many projects are becoming available. Examples he cited included the *NCHRP Web-Only Document 231: Challenges to CV and AV Application in Truck Freight Operations*, and *NCHRP Report 845: Advancing Automated and Connected Vehicles: Policy and Planning Actions for State and Local Transportation Agencies*. Two other reports that will be available in the fall of 2017 are *Impacts of Regulations and Policies on CV and AV Technology Introduction in Transit Operations* and *Road Markings for Machine Vision*.

Pedersen noted that other projects underway include Dedicating Lanes for Priority or Exclusive Use by CVs and AVs; Implications of Automation for Motor Vehicle Codes; and Providing Support to the Introduction of CV/AV Impacts into Regional Transportation Planning and Modeling Tools. Two other projects are Business Models to Facilitate Deployment of CV Infrastructure to Support AV Operations and Cybersecurity of Traffic Management Systems.

Pedersen discussed recent TRB convening and connecting opportunities related to CAVs. The 2017 TRB Annual Meeting included more than 50 sessions on CAVs. He noted that TRB expects that the 2018 97th Annual Meeting in 2018 feature even more sessions. According to Pedersen, the 2017 AVS is second only to the Annual Meeting in attendance. TRB continues to host webinars on a wide range of topics related to CAVs.

Pedersen described the National Academies/TRB Forum: Preparing for AVs and Shared Mobility, which is a new activity underway at TRB. The objective of the forum is to bring together partners to discuss, identify, and facilitate fact-based research needed to deploy AVs

and shared-mobility services in a manner and timeframe that informs policy to best meet long-term goals, and to share perspectives on these issues. He noted that the long-term goals include increasing safety, reducing congestion, enhancing accessibility, increasing sustainability, and encouraging economic development and equity.

Pedersen reported that an organizing meeting for the forum was held on Monday before the start of the AVS. Participants identified issues, opportunities, and possible research topics associated with transformational technologies and shared mobility services. He noted that more than 20 public and private-sector organizations have signed up to participate in the forum or have expressed interest.

In closing, Pedersen extended an invitation to attend the 97th Annual Meeting of the Transportation Research Board in Washington, D.C., January 7–11, 2018. Pedersen provided the following websites to obtain more information on TRB.

- For more information on TRB, visit www.TRB.org.
- For more information on TRB Transformational Technologies activities, visit www.TRB.org/TransTech.aspx.
- To get involved, go to www.MyTRB.org.

Commemorating the 20th Anniversary of the National Automated Highway Systems Consortium Demo '97 in San Diego

RICHARD BISHOP

Bishop Consulting

KEVIN DOPART

U.S. Department of Transportation

STEVEN SHLADOVER

PATH, University of California, Berkeley

Richard Bishop, Kevin Dopart, and Steven Shladover discussed the National Automated Highway Systems Consortium (NAHSC) Demo '97, which was conducted in San Diego. They presented a video and photographs highlighting different elements of the technical feasibility demonstration.

The basis for the NAHSC demonstration was Section 6054(b) of the Intermodal Surface Transportation Efficiency Act of 1991, which induced the following language: “The Secretary shall develop an automated highway and vehicle prototype from which future fully automated intelligent vehicle–highway systems can be developed. Such development shall include research in human factors to ensure the success of the man–machine relationship. The goal of this program is to have the first fully automated roadway or an automated test track in operation by 1997.”

The U.S. DOT held a competition to select the consortium to conduct the program. The winning team was led by General Motors (GM) and included Delphi Automotive (Delco Electronics), Hughes Aircraft, Lockheed-Martin, Bechtel, and Parsons-Brinckerhoff. Other team members were Carnegie-Mellon University (CMU), the UC PATH Program, and Caltrans.

The demonstration was intended to be just one of the milestones in the program. A post-demonstration roadmap toward deployment included the development of a prototype and the definition of a specification for a deployable system. The program was terminated shortly after the demonstration, however, because the language in the Act had been met.

Demo '97 was conducted in San Diego August 7–10, 1997, using the I-15 HOV lanes. The adjacent Miramar College campus was also used for exhibits and mini-demonstrations.

There were seven different demonstrations that offered rides to people. The first two scenarios were conducted by the NAHSC core team. The Free Agent Multi-Platform Demonstration included two buses and two cars; CMU, GM, Delphi, Hughes, and Houston Metro conducted the demonstration. PATH, GM, Delphi, and Hughes conducted the eight-car platooning demonstration. The associate demonstration included a two-car control transition scenario by Honda, a two-car evolutionary scenario by Toyota, and alternative technology scenario using a radar reflective pavement stripe by Ohio State University. Other associated demonstrations included a collision warning system with a truck and a target car by Eaton Vorad and a highway maintenance demonstration involving two maintenance vehicles by Caltrans and the UC Davis Advanced Highway Maintenance and Construction Technology Program.

The Demo '97 statistics included 21 vehicles driving over 8,000 automated miles. The exhibit drew 3,500 visitors, while the mini-demos attracted 3,100 riders and the on-road demo attracted 2,850 riders. The media coverage included all the national television stations, National

Public Radio's "All Things Considered," and the major newspapers. International coverage included 12 countries on five continents. A total of 120 media outlets were represented covering the Demo. Numerous dignitaries also attended the events.

The different demonstrations were highlighted in a video. Demo '97 shifted thinking on a global level that automation was possible. The Demo '97 legacy continues with CAVs. The NAHSC technical reports and Demo '97 information are posted online at <http://www.path.berkeley.edu/publications/national-automated-highway-systems-consortium>.

Drones, Loops, and Robotaxis *A City Roadmap to Our Hyper-Uber Future*

SELETA REYNOLD

Los Angeles Department of Transportation

Seleta Reynolds discussed programs and activities underway at the Los Angeles DOT associated with AVs and transformational technologies. She noted that technology and automation were key drivers of the rapid changes occurring in Los Angeles and in other cities throughout the country.

Reynolds reviewed the three focus areas for Los Angeles DOT. The first focus area is safe great streets, which includes a goal of zero fatalities by 2025. The second focus area is mobility management and providing equitable, reliable, and affordable travel options for residents and visitors. The third focus area is internal, ensuring a great work environment at Los Angeles DOT and engaging employees in achieving the agency's goals.

Reynolds reported that approximately 260 fatalities occur annually on the city streets from traffic crashes. Thus, the goal is to reduce traffic deaths to zero by 2025. Although pedestrians and bicyclists are involved in only 15% of these collisions, they account for almost half of the fatalities. She noted that children and older adults are overrepresented in the fatalities. She further noted that traffic crashes are the number one cause of death for children in Los Angeles County under 14 years of age. She called the situation an urgent and preventable public health crisis.

Reynolds reported that traffic fatalities in Los Angeles increased by 35% over the previous year, with two-car crashes resulting in the death of one of the drivers increasing by 50%. She noted that while many factors may be influencing these trends, including lower fuel prices and a robust economy, the use of some type of technology by drivers may also be contributing to the increases in fatalities. She suggested that technology could enhance the transportation system or it could distract drivers and pedestrians and increase crashes before full automation is reached.

Reynolds noted that AVs will play a key role in achieving Vision Zero. She discussed the potential impacts of different paths to a fully automated vehicle fleet. One path reflects an iterative approach of taking over driving functions over a number of years. Another path would accelerate the automation of driver functions. She noted that the second approach may be more powerful in reaching Vision Zero.

Reynolds suggested that automated shared mobility could help redefine public transit and provide better service to all parts of the city. Reynolds suggested that AV technology will reshape the transportation infrastructure of Los Angeles. She noted that nationally 94% of crashes are caused by human error. There are approximately 4 million people and 7.5 million motor vehicles in Los Angeles. Los Angeles ranks first among cities with the worst traffic congestion. She suggested that shared AVs could help reduce the number of vehicles in the city while improving efficiencies. Reynolds described some of the potential benefits of AVs, including not having to widen roadways or build more parking garages. She reported that Los Angeles DOT manages Valet Parking Permits, which contribute almost \$2 million to the city's annual general fund budget. She noted that restaurants and clubs are not purchasing as many Valet Parking Permits because patrons are using Uber and Lyft.

Reynolds described the accessibility to jobs in Los Angeles by transit and by automobile. Currently, 12 times as many jobs can be reached by automobile in an hour than by transit. She stressed that transportation has to provide people with connections to opportunities. She compared the reach of the Metrorail system with the service areas of Uber and other transportation network companies (TNCs). Much of the TNC service area also has frequent bus and rail service. She noted that research is needed examining the impact of TNCs on transit use, bicycling, and walking. While there is a lot of anecdotal evidence, accurate information is lacking on the possible impacts of TNCs on these modes and on traffic congestion.

Reynolds discussed the development of a transportation technology strategy for Los Angeles. The strategy, presented in the *Urban Mobility in a Digital Age* report, presents a framework or platform for innovation. The platform focuses on setting public policy and structuring investments to prepare for the arrival of connected, automated, shared, and EVs. The five elements include building a solid data foundation, leveraging technology and designing for a better transportation experience, creating partnerships for more shared services, supporting continuous improvement through feedback, and preparing for an automated future.

Reynolds noted that a fully automated transit system was part of the future. She reported that Los Angeles has the largest municipal transit system in the country, which includes 300 contracted services vehicles. She suggested that the city has the opportunity to grow the size and shape of the transit fleet.

The platform also includes the three key concepts of data as a service, MaaS, and infrastructure as a service. Reynolds described possible elements of data as a service, which focuses on the rapid exchange of real-time data on transportation conditions. Information may be exchanged between customers, service providers, government agencies, and the infrastructure to optimize safety, efficiency, and the transportation experience. Data sharing agreements with Waze and other similar companies provide one example of this approach.

Reynolds discussed infrastructure as a service, which focuses on a dynamic pay-as-you-go approach to more closely align the costs of providing infrastructure with how it is used. Providing improved information on on-street parking schedules and costs, along with more convenient payment methods were examples of this approach cited by Reynolds. She suggested that temporary infrastructure may play a more important role in the future, such as creating temporary pop-up bike lanes.

Reynolds described the MaaS approach, which includes GoLA, an app that provides access to a suite of transportation mode and payment options through a single platform to simplify access to mobility choices. She noted that GoLA is a partnership with Xerox. She highlighted the LA Promise Zone, which provides one example of the MaaS approach. Using funding from a number of sources, the LA Promise Zone will include developing mobility hubs in a low-income area, which bring together car-sharing, bike-sharing, green taxi fleets, and transit. It will also include community enhancements and treating residents with respect. Reynolds noted that the city is also investing in infrastructure and communication technology, safer street design, an on-demand city transit pilot, and WiFi kiosks.

Reynolds described the coordinated efforts of Los Angeles DOT, Los Angeles County, and Metro to identify proving grounds for testing and piloting different levels of AVs. She reviewed the locations that have been identified to date within the region. The Palmdale airport provides an enclosed environment. The UC Los Angeles campus and the Playa Vista Tech Campus in Silicon Beach provide semi-enclosed environments. The Promise Zone is an

underserved area in the urban core near downtown Los Angeles. Caltrans and PATH have created the Connected Corridor on the I-210.

Reynolds highlighted some of the 50 partnerships being explored with these activities. She noted that partnerships are critical, but matching partners to the key technology strategies and objectives is also important. In closing, she stressed the importance of focusing on how AVs can benefit cities and people.

Future of Urban and Autonomous Mobility *Bringing Autonomy on and Beyond the Streets of Boston*

ANDREY BERDICHEVSKIY
Automotive Lead, Practice Lead Urban Mobility
World Economic Forum

Andrey Berdichevskiy presented on the collaboration between the World Economic Forum and the City of Boston, in partnership with the Boston Consulting Group, to pilot AV applications in the city. He summarized the Forum's initiative to make self-driving vehicles a reality: form-defining options for precompetitive elements over developing a business and operation model strategy up to supporting the launch of current pilots in Boston.

Berdichevskiy discussed the World Economic Forum's objectives making self-driving vehicles a reality. In addition to improved road safety, which is typically mentioned as a benefit, he also noted that AVs have the potential to reduce public transport spending, decrease pollution, and provide more-reliable, -efficient, and -equitable transportation. He suggested that the benefits from shared services and partial automation may be realized sooner than some of the safety benefits.

Berdichevskiy reported that the World Economic Forum is an international nonprofit institution committed to improving the state of the world through public-private cooperation in the spirit of global citizenship. He noted that the Forum began examining self-driving cars and shared services in 2014. In partnership with the Boston Consulting Group, the Forum developed a roadmap of the elements that should be considered when bringing self-driving vehicles to the marketplace. In 2015, the Forum conducted a survey of 5500 urban dwellers in 10 countries worldwide to gauge interest in self-driving vehicles. Interviews were also conducted with city policymakers to obtain insights into local concerns and possible regulations.

In 2016, the Forum partnered with the City of Boston to develop a vision for mobility and a strategy for AV deployment and AV testing. He noted that the AV strategy includes the movement of goods. He also noted that the partnership also contributes to a network of cities to share best practices and experience on a global level.

Berdichevskiy reviewed the activities and tests that have been completed since the partnership was announced in September 2016. Examples included on-road testing of nuTonomy, and partnerships with OPTIMUS RIDE, Delphi, and Lyft.

Berdichevskiy discussed the phased incubator approach used in Boston to scale technology and business model trials in a controlled environment. The testing phases include off-site testing, initial testing in the Raymond Flynn Marine Park Seaport District, and expanded testing in the South Boston Waterfront and other areas.

Berdichevskiy described the development of a real-life traffic model for downtown Boston in partnership with the MIT and the Boston Consulting Group. The agent-based model incorporated geospatially data to simulate traffic and pedestrian flows on downtown streets.

In addition to examining current conditions, the model was used to assess two scenarios. The evolutionary scenario focused on a shift to autonomous technology with a conservative increase in vehicle sharing. The revolutionary scenario included a disruptive shift to shared, autonomous transportation. Called the Robo-Transport Revolution, this scenario included a shift from personal car to shared self-driving taxis and minibuses.

Berdichevskiy noted that the modeling results of the two scenarios, which illustrated considerable reduction in the number of vehicles due to shared mobility. The private car evolutionary scenario resulted in an 11% reduction of vehicles, while the Robo-Transport Revolution scenario resulted in a 28% reduction in vehicles. The Robo-Transport Revolution scenario resulted in a 30% reduction in average travel time while the private car evolutionary scenario resulted in an 11% reduction. The Robo-Transport Revolution scenario also resulted in larger reductions in both CO₂ emissions and parking spaces.

Berdichevskiy concluded by highlighting six key takeaways from the collaboration to date with the City of Boston. A first takeaway was that AVs are a crucial building block to making transportation more accessible, safe, and reliable. A second takeaway was that AVs enhance, but do not replace public transit. A third takeaway was that getting used to AVs takes time and that the public's awareness of them must be created early on. A fourth takeaway was that the City of Boston does not want to own assets for shared-mobility models. A fifth takeaway was that Boston envisions one citywide mobility platform where all its mobility offers converge. A final takeaway was that experimentation with different industry partners, in close cooperation with the state level, was key to learning.

Berdichevskiy closed by describing the five key topics examined in 2017. The first topic was urban logistics models and analyzing new business models for urban goods delivery. The second project objective was assisting in expanding AV testing in Boston. The third topic focused on broadening the scope of traffic simulation to better understand the impacts of AVs in different areas of the city and consumer preferences for the choice of modes once autonomy becomes reality. The fourth objective was to developing a framework for a city mobility platform. The fifth topic focused on sharing experiences at the global level about leveraging digital capabilities and existing city networks and collaborations to advance AVs.

Trucking Automation Technology Developments *Panel Discussion*

RICHARD BISHOP

Bishop Consulting, moderator

MICHAEL CAMMISA

American Trucking Associations, panelist

MAX FULLER

U.S. Xpress, Inc., panelist

JOSH SWITKES

Peloton Technology, panelist

ALDEN WOODROW

Self Driving Trucks, Uber Advanced Technologies Group, panelist

KELLY REGAL

Federal Motor Carrier Safety Administration, panelist

ARAVIND KAILAS

Volvo Group North America, panelist

Richard Bishop opened the session by describing some of the factors currently affecting the trucking industry, including a shortage of drivers, hours of service regulations, fuel costs, and crashes. Other factors cited by Bishop were traffic congestion, sustainability, and truck size and weigh regulations. He also noted that the increase in parcel delivery to residential addresses is impacting the trucking industry.

Bishop discussed different truck automation use cases. He noted that fuel economy and increased productivity are key factors driving the interest in truck platooning. The different use cases at different automation levels highlighted by Bishop included two-truck platooning, traffic jam assist, highway pilot, automated trailer backing, and parcel delivery automation. He also noted that higher automation levels can be achieved in constrained environments, such as trailer switching at private distribution centers, trucks used in mining operations, and drayage trucks at ports.

Bishop suggested that driver assisted two-truck platooning is a near term option, which could result in fuel savings of up to 5% for the leading truck and approximately 10% for the following truck. He noted that early projects will use Level 1 technologies that are currently available. The driver in the following truck is responsible for steering and monitoring the driving environment. The following driver can also take over control at any time. He suggested that the role of the driver in the following truck may evolve over time based on public acceptance and regulations, and platoons may include more than two trucks.

Bishop provided information on the possible use of truck automation with drayage at the Port of Palm Beach in Florida to address traffic congestion at the gate. The port provides a relatively low-risk environment for piloting automation drayage trucks, with numerous benefits.

Bishop reviewed other concepts including Level 4 highway driverless trucks from entrance ramps to exit ramps, remote-controlled trucks on local roadways, and private property driverless trucks. He noted that all of these concepts are attracting investments.

Kelly Regal summarized the Federal Motor Carrier Safety Administration (FMCSA) roadmap for addressing automated commercial vehicles. The roadmap includes the short-, mid-, and long-term goals and the focus areas. She noted that the overall goal is to enable the safe operation of highly automated commercial motor vehicles on the nation's transportation system to improve safety, prevent crashes, and efficiently move passengers and commerce. The FMCSA mission is to develop and enforce rules and regulations for the safe operation of motor vehicles on the nation's highways.

Regal noted that the FMCSA and U.S. DOT encourage innovation in the industry, as well as open communication and transparency. She stressed the importance of the safe operation of automated driving systems. She challenged symposium participants to develop technologies to assist with inspection, repair, and maintenance.

Regal described the focus areas in the roadmap and some of the current activities. She noted that focus areas include policies, pilot projects, and data needs. The current FMCSA rules and regulations are being reviewed to identify possible changes to address automation. Research and development is also underway in collaboration with FHWA on truck platooning and with NHTSA on cybersecurity.

Regal described FMCSA's stakeholder engagement activities. She noted that the law enforcement community is asking for information on automated trucks and buses. FMCSA has conducted workshops and listening sessions to provide information and to request feedback on designing, developing, testing, and deploying highly automated commercial vehicles (HACVs).

Michael Cammisa reported that the American Trucking Association represents trucking fleets, truck OEMs, technology developers, and Tier 1 suppliers. He noted the diversity in the trucking industry and the variety of ways trucks are used to provide different types of services. There are also a variety of technologies that can be applied to these different services. He stressed the importance of policies that provide flexibility for innovation in developing and applying technologies to these different services.

Cammisa discussed the importance of considering different business models. There has to be a business case and a return on investment (ROI) for trucking companies to purchase automated technologies. Possible ROIs could relate to fuel savings, increased productivity, or improved safety. He described a built-in evaluation process. He noted that technology companies need to prove that a product is safe to have a business case and that trucking companies are only interested in purchasing a safe product.

Cammisa suggested that the uncertainty related to policy development, infrastructure needs, and deployment paths adds complexity to the current situation. He noted that ongoing conversations among all groups are beneficial to advance the development of commercial vehicle applications.

Max Fuller reported that U.S. Xpress, Inc., was the fourth or fifth largest truck-load carrier in the country and the fifth largest carrier in Mexico. U.S. Xpress has been an early adopter of technology throughout its 31 years in operation. He noted that an ROI within 18 to 24 months is typically needed to consider a technology application at U.S. Xpress. He further noted that trucks are traded out before they accumulate 500,000 mi, which typically occurs in a 4- to 5-year period.

Fuller reported that the current focus is on driver assist and safety enhancement technologies. He noted that the initial reaction from truck drivers to AVs is that they will lose their job. Fuller said that U.S. Xpress stresses that technology improves their safety and productivity, creates a better ROI for the company, and provides better service for customers.

Fuller stated that U.S. Xpress trucks are currently operating at Level 1 to Level 2, with autonomous braking, collision avoidance, automated transmissions, and disk brakes. He stressed the safety benefits of these technologies. He also stressed that these features also enhance truck driving jobs that people want.

Aravind Kailas described the Volvo Group's recent activities in truck automation. He noted that the Volvo Group is the leading manufacturer of trucks, buses, construction equipment, and industrial-grade marine engines. He further noted that the Volvo Group believes that CVs and automated driving are interconnected and will play a vital role in reshaping the cities of tomorrow. The Volvo Group has invested in ongoing research and development projects, as well as technology demonstrations in the United States and in Europe. He acknowledged that these activities have been undertaken with numerous partners from the public and private sectors.

Kailas highlighted examples of automated commercial vehicle projects Volvo has participated in, including a truck platooning demonstration near the Port of Los Angeles, the European Truck Platooning Challenge, and a self-steering truck demonstration in Brazil. Examples of Volvo autonomous truck demonstrations include a driverless mining truck and an autonomous refuse truck. He noted that the business case for the autonomous mining truck was removing human drivers from potentially hazardous situations. The business case for the autonomous refuse truck is reducing safety risks for operators.

Kailas emphasized that CAV go hand-in-hand because highly automated driving systems and fully autonomous driving systems can leverage data from other vehicles and the infrastructure to enhance their performance. He noted that with funding from the U.S. DOT, the Volvo Group and other OEMs developed, demonstrated, and conducted field trials of three safety applications leveraging data from the infrastructure.

In summarizing the takeaway from his comments, Kailas suggested that there is no one solution or technology. Rather, he noted that there are a variety of great technology options, with the choices dictated by customer needs and applicability to business area.

Josh Switkes presented videos of truck platooning. He noted that Peloton Technology focused on the commercialization of truck platooning. He described some of the technologies and application illustrated in the videos, including connected braking. He noted that V2V communications allows for the synchronization of trucks, which provided a new level of safety and efficiency.

Alden Woodrow discussed Uber's expansion into moving goods as well as people. He noted that the Uber Advanced Technologies Group is focused on developing self-driving cars and trucks. He stressed the important role trucks play in moving goods in the United States. Trucks move about 250 lb of goods per person every day in the United States and drive approximately 170 billion miles a year. He noted that while the safety record of trucks is good given the high mileage, Uber's goal is to eliminate all fatal crashes. As a product manager, Woodrow's role is to take the promising technology Uber is developing and turn it into safe, reliable, commercial products.

The panelist responses to questions from the moderator and the audience include the following.

- Panelists described differences in the risks associated with heavy vehicle automation and light vehicle automation. Panelists noted that while the risk categories are similar, the actual risks, as well as the use cases, are different. For example, the braking distance of a truck is much longer and more variable than a car and the equipment on a truck is less predictable with the potential for different trailers. Use case differences include more highway miles for trucks, which make exit-to-entrance truck automation applications beneficial. Further, trucks use air brakes and passenger vehicles use hydraulic brakes, which enhances the value of V2V communication by synchronizing the application of brakes and eliminates the time lag between vehicles. Applications in industrial yards may be different, and face different challenges that those on freeways.

- Panelists discussed regulations related to truck platooning. At the state level, laws associated with vehicle following distance and tailgating would also apply to truck platooning. Panelists noted that most of these laws do not specify a distance or a time headway, but use language requiring a “reasonable and prudent” following distance. Panelists reported that at least nine states have legislation authorizing truck platooning. Panelists further noted that the initial truck platooning projects use Level 1 and Level 2 automation, with a driver in the following truck. At the federal level, the FMCSA is currently assessing the impact of automation on current Federal Motor Carrier Safety Regulations. The NHTSA has FMVSS that apply to the construction of commercial vehicle and FMCSA has regulations that address the operational aspects of technology.

- Panelists discussed potential applications of automated driving technologies with commercial vehicles, customer interest, and the value proposition of different approaches. One suggestion, which would require changes in regulations, was truck platooning on long-haul service, with the driver in the following vehicle allowed to sleep. Panelists discussed the remote operator application that involves controlling trucks remotely from an Interstate exit to a distribution center or other destination. Some panelists suggested that public acceptance and the complexity of operating with urban environments may be obstacles to this alternative.

- Panelists discussed the potential impact of automation on the hours-of-service regulations. Approaches that would enhance driver productivity, such as using traffic jam assist to gain hours of service back, were discussed. The potential of using the FMCSA waivers for developer demonstrations and temporary exemptions to test scenarios that would require the request of a waiver or an exemption to the hours-of-service regulation was discussed.

- Panelists discussed the possible impacts of automation on jobs in the trucking industry, especially truck drivers. Some panelists noted technology is complementary to drivers and the industry. Panelists also noted that technology can enhance driver’s jobs, employment, and the overall productivity of the industry. It was suggested that automation can transform the types of jobs in the trucking industry.

- Panelists discussed the possible deployment schedules for different truck automation applications. There was general agreement that Level 1 and Level 2 automation would be in use by 2030. Higher levels of automation would follow, except in target application such as mining which are already being used.

Shared Mobility Panel

KELLEY COYNER

*Schar School of Policy and Government Center for Regional Analysis
George Mason University, moderator*

JEFF HOBSON

San Francisco County Transportation Authority, panelist

JOSEPH OKPAKU

Lyft, panelist

ADAM GROMIS

Uber, panelist

Jeff Hobson noted that San Francisco was proud to be the headquarters and a laboratory for many of the emerging mobility services, including Uber, Lyft, and companies in the AV sector. He noted that San Francisco is proud of its history as a place that envisions how to make the future better. For example, the United Nations was founded in San Francisco. People, agencies, and companies think they can create a better future and a better world. He suggested that this perspective was important in the local approach to shared mobility services.

Hobson described two important roles of the San Francisco County Transportation Authority (SFCTA) related to AVs. These roles focus on being a regulator and innovator. As an innovator, he noted that San Francisco applied for the federal Smart Cities Challenge and was one of the finalists. Although San Francisco was not selected as the winner, he reported that it did receive one of the follow-on grants. A portion of that grant is being used to test an autonomous shuttle on Treasure Island, which is being transformed from a naval station to mixed-use development. Located in the middle of the Bay Bridge, Treasure Island currently has a population under 2,000 people. He noted that with a projected population of 25,000 people, the island and the Bay Bridge will not function if everyone drives alone. An AV shuttle on the island is one of the solutions to addressing these concerns.

While the test will include an assessment of the autonomous shuttle technology, Hobson said an important and interesting innovation was integrating AVs into a MaaS platform. He noted that integrating the autonomous shuttles into a smartphone app that also provides access to ferries, buses, ride hailing, bike-sharing, car-sharing, and other modes was a key part of the project. He commented that providing consumers with one app to obtain access to all services was important to providing mobility enhancements. He further noted that the app could be used to offer incentives for the use of different modes.

Hobson reviewed the project timeline, which included testing the autonomous shuttle in approximately 18 months. He also described the opportunities for industry and private-sector partnerships, which are key elements of the project.

Hobson discussed the SFCTA's role as a regulator. Noting that San Francisco was a hot bed of innovation, he stressed the importance of considering how all the new mobility services and TNCs are going to work together. He commented that some residents view Uber, Lyft, and

other TNCs as new mobility services, while other residents are concerned about the impact of these services on traffic congestion.

Hobson suggested that TNCs can be viewed as the first version of shared AVs. He noted that people using TNCs do not know what type of vehicle they will use. Further, they step into a vehicle owned by someone else, they let someone else do the driving, and they use their time in the vehicle to do nondriving activities. He noted that gaining a better understanding of how the various TNCs and mobility services work and how they can support San Francisco's vision was important.

Joseph Okpaku discussed the origins of Lyft. He noted that the predecessor to Lyft was a company called Zimride, which was named after the country of Zimbabwe, where one of the co-founders first experienced shared-ride services. He noted that shared rides are part of the Lyft DNA. Lyft was launched on the concept of filling the available seats in people's vehicles. He noted that Lyft Line was implemented as the next natural progression of this concept.

Okpaku described Lyft Line, which provides an option for two strangers to share the same ride to the same or common destination. He reported that approximately 40% of Lyft rides are Lyft Line rides in most major cities, which suggests that the idea of sharing rides is becoming acceptable. Okpaku noted that Lyft is working in partnership with a number of transit systems to provide first-mile and last-mile service. He suggested that AVs will provide opportunities to right-size vehicles based on the number of passengers, as well as address the special needs of any riders.

Okpaku said that Lyft is using an open platform approach to encourage partnerships with multiple companies. He noted that Lyft currently has partnerships with GM, Waymo, and nuTonomy to examine demand and test different service concepts to provide efficient service, reduce VMT, encourage shared use, and reduce car ownership.

Okpaku noted that Lyft was still a young company with the opportunity to expand shared mobility options through innovative services and partnerships with transit systems, OEMs, technology companies, and other groups.

Adam Gromis reviewed Uber's mission, which is to bring reliable transportation to everyone everywhere. He noted that self-driving technology has a major role to play in achieving this mission. He highlighted three trends that are colliding—shared mobility, electrified mobility, and automated mobility. He noted that Uber is working with others to ensure positive outcomes from all three trends.

Related to shared mobility for ridesharing, Gromis reported that Uber has invented a platform that 2 million drivers in 76 countries use to offer their services for some 10 million trips per day. He noted that these trips account for approximately 1.2 billion miles per month. He reported that Uber is also mapping cities, which is key for self-driving vehicles, and leaning about travel behavior and trip-making patterns.

Gromis reported that the Uber platform in North America includes thousands of EVs, traveling millions of miles offering zero tailpipe emissions rides. He noted that Uber has recently conducted pilots in nine cities around the world involving more than 200 EVs to learn more about facilitating the adoption of EVs in ridesharing.

Gromis described Uber's advanced technologies group, which is focusing on both self-driving cars and trucks. He noted that demonstrations are underway in Pittsburgh, Pennsylvania, and Phoenix, Arizona. Uber customers using the UberX app are able to access self-driving vehicles, which actually have two operators. He also reported that self-driving trucks using low levels of automation are being tested in California.

Gromis noted that positive results are being realized from the early tests and pilots for all three trends. He suggested that continuing to expand partnerships will be important to ensure that the benefits from advanced technologies and ridesharing services are realized.

Panelists discussed the following topics in response to questions from the moderator and the audience.

- The panelists discussed the automation of a networked company's vehicle fleets. The responses indicate that companies anticipate continuing to move toward more AVs, as well as driver-based platforms, in urban centers. Panelists suggested that shared rides will continue to increase in these areas and that ownership of personal vehicles will decline. Panelists discussed the pilots underway in many cities. It was further suggested that the increase in automated EVs will provide opportunities for re-designing and re-shaping urban centers into more people-centric places.
- The panelists discussed different types of services, potentially using different types of vehicles, for urban, suburban, and rural markets. Coordinating these services with public transit and other services was noted as important by panelists, such as providing first- and last-mile links. The differences in geography and travel patterns in various cities were discussed by panelists. The panelists discussed the wide range of public- and private-sector groups involved in the AV area. The interest of OEMs and start-up companies was noted by participants.
- The potential impacts of AVs, shared services, and EVs on traffic congestion, VMT, mobility, safety, and equity was discussed by panelists. Some panelists suggested the need to revise the transportation planning process to better reflect these new services. The need to re-examine goals, policies, and performance metrics for these new services was also suggested by panelists. The need to avoid unintended consequences was discussed.
- Panelists discussed that TNC users may be early adopters of AVs. Panelists also discussed different incentives to encourage ridesharing.
- Panelists discussed the interaction of TNCs and local governments, including policies, infrastructure, data sharing, and transparency. Considering the needs of local governments, consumers, the public, and TNCs in these activities was suggested as important by panelists.

Identifying and Addressing Nontechnical Key Research Questions *Infrastructure*

SHAILEN BHATT

Colorado Department of Transportation

Shailen Bhatt provided a perspective from state DOTs. He noted that the purpose of the Colorado DOT is to save lives and to make lives better by providing freedom, connection, and experiences through travel. He said that AV technologies could help save lives and make lives better. He noted that AV technologies can reduce traffic fatalities, which increased in 2016 after decreasing for a number of years.

Bhatt described the major responsibilities of Colorado DOT. The agency's 2017–2018 budget is approximately \$1.42 billion. He noted that Colorado DOT maintains and operates some 23,000 total lane miles of highways and 3,454 bridges. The agency administers \$208 million each year in federal grants and Colorado DOT's Division of Transit and Rail administers federal and state grants.

Bhatt discussed the challenge of meeting the needs of a growing state. In 1991, Colorado was home to approximately 3.5 million people. The 2015 population of the state was 5.4 million people. He noted that the population is forecast to increase to 7.8 million people by 2040. The number of registered vehicles in the state and VMT reflect similar growth trends. There were 3.3 million registered vehicles in 1991, 5.5 million in 2015, and projections are for 7.8 million vehicles by 2040. VMT increased from 27.7 billion in 1991, to 50.5 billion in 2015, and is projected to increase to 72.3 billion by 2040. At the same time, he noted that the amount spent on transportation per person, adjusted for inflation, has declined from \$125.70 in 1991 to \$68.94 in 2015, with a projection of \$41.16 per person in 2040.

Bhatt described RoadX, which focuses on accelerating technology deployment in the state. He noted that the RoadX vision is providing crash-free, injury-free, delay-free, and technologically transformed travel in Colorado. Further, the RoadX mission is to team with public and industry partners to provide Colorado with one of the most technologically advanced transportation systems in the nation, and to become a leader in safety and reliability.

Bhatt stressed that RoadX focuses on the deployment of technological solutions in partnership with the private sector. He described the connected road classification system, which includes six levels. Level 1 is unpaved and/or nonstriped roads designed to a minimum standard of safety and mobility. Level 2 is paved roads designed to the American Association of State Highway and Transportation Officials standards with the *Manual on Uniform Traffic Control Devices* (MUTCD) signage. There is not ITS equipment or infrastructure to collect connected vehicle data, but cellular data service may be available. Level 3 includes ITS equipment operated by a Traffic Operation Center (TOC) and/or one-way electric data sharing between a DOT, a vehicle, a user, and/or mixed-use traffic lanes.

In Level 4, the roadway or specific lane has adaptive ITS equipment with TOC override only, and/or two-way data sharing between a DOT, vehicles, users, and/or lanes designated for SAE Level 3 and Level 4 vehicles only. Level 5 includes advance guideway system roadways or specific lanes designed for vehicle SAE Level 4 only with additional features that may include inductive charging, advanced/enhanced data sharing, and other features. Additionally, no roadside signs are needed as all roadway information is sent directly to the vehicle's onboard

systems. Finally, in Level 6, all roadway elements are designed for only SAE vehicle Level 5 systems, with no signs, signals, or striping needed.

Bhatt described some of the RoadX projects and partners. Smart 25 focuses on software and sensor upgrades to better manage traffic flow. Smart 70, from Golden to Vail, is a partnership with HERE that will provide real-time data on hazards, including visibility, sun glare, and multivehicle crashes. He noted that Smart 70 also includes a partnership with Panasonic for self-driving vehicles and infrastructure data sharing to reduce crashes, increase capacity, and improve travel-time reliability.

Other innovative projects described by Bhatt included self-driving truck platooning, and smart parking in partnership with Otto (the self-driving truck subsidiary of Uber). He also noted that Colorado was one of the finalists in the Hyperloop One Challenge. In addition, Colorado DOT is exploring a Smart Powered Lane, and plans to pilot embedded charging in roads to power EVs.

Serving the Needs of All Through Better Design

EDWARD STEINFELD

*Center for Inclusive Design and Environmental Access
State University of New York at Buffalo*

Edward Steinfeld described the use of universal design to enhance AVs and ensure equitable transportation. He introduced the Center for Inclusive Design and Environmental Access (IDEA Center) at the University of Buffalo, which is part of the State University of New York System. Founded in 1984, he noted that the primary goal of the IDEA Center is to produce knowledge and tools that will increase the quality of life for groups who have been marginalized by traditional design practices. He further noted that the IDEA Center is a multidisciplinary research center with architects, urban planners, occupational therapists, industrial engineers, and social scientists.

Steinfeld noted that the IDEA Center is considered a leader in research and development center on universal design and environmental accessibility in North America. He reported that IDEA research includes laboratory studies using full-scale simulations, field research, usability testing, surveys, and focus groups. Publications include the first comprehensive text on universal design, *Inclusive Design: Implementation and Evaluation*, and a book on accessible public transportation, *Accessible Public Transportation: Designing Service for Riders with Disabilities*.

Steinfeld noted that in a just society, AVs should provide benefits to all segments of society. He suggested that it is not sufficient to “design for disability” alone, because people are not defined solely by their ability. He commented that avoiding inconvenience, stigma, and embarrassment are as important for people with disabilities as they are for everyone.

Steinfeld said that the philosophy of universal design provides a holistic framework for conceiving, designing, and operating inclusive transportation systems. He noted that universal design addresses issues beyond function, that it is market driven rather than regulation driven, and that it is aspirational.

According to Steinfeld, universal design in AV systems requires a service design approach. In addition to addressing the physical design of the vehicle, it also has to address communications, the user interfaces for hailing and operation, pricing structures, response times, driver training, and many other factors.

Steinfeld said that universal design is a process that focuses on making things easier to use, healthier, and friendlier. He suggested that embracing universal design means working continuously to improve usability, reduce accidents and injuries, and increase the social value of an environment, product, or system.

Steinfeld described eight goals of universal design developed at the IDEA Center to conceptualize the desired outcomes in ways that can be measured and evaluated. Four of the goals—body fit, comfort, awareness, and understanding—focus on human performance. The fifth goal—wellness—addresses accident prevention, disease prevention, and health promotion. The final three goals—social integration, personalization, and cultural appropriateness—focus on social participation.

Steinfeld described the video of Steve Mahan, a man who lost 95% of his vision, operating a Google self-driving car. He noted that the video captures the promise of automated transportation for many groups of people. He also noted that many people are not as mobile as

Mahan. For example, Mahan can walk and he can climb in and out of a small vehicle. He has the judgement to make good decisions. He can speak clearly and in a language understood by speech recognition systems. He is also not afraid to put trust in technology. Further, he may have resources to pay for the ride.

Steinfeld commented that many people do not have all of Mahan's capabilities. He suggested that to serve the full spectrum of riders, AVs must offer the same opportunities to all groups of people, including children, older people who can no longer drive, people who use wheelchairs and other mobility devices, people with cognitive limitations, and those at risk of acute health problems. He also noted that social issues need to be addressed, including income and discrimination based on race, sexual orientation, gender identity and ethnicity, in addition to disabilities.

Steinfeld discussed the potential for AVs to reduce dependency for people who cannot drive. He noted that this group could be a target market for early adoption of AVs. Additionally, systems designed for these groups are likely to address issues that other riders might face. He suggested that serving this population segment could be a testing ground for technologies to be introduced to the broader market.

Steinfeld described the vans equipped with wheelchair lifts commonly used today in paratransit operations. He also highlighted a low-floor shuttle bus designed and produced by Volvo over 15 years ago to provide better access for older riders. He suggested that more innovation is needed for accommodating individuals on wheelchairs with AVs.

Steinfeld noted that many TNCs and ride-hailing systems have opted to provide a limited number of accessible vehicles, resulting in longer response times for people who need them. He suggested that adopting accessible vehicle designs more broadly, similar to what taxi fleets have done in many locations, would be beneficial. He also noted that current AV shuttle buses under development are not accessible enough to meet minimum standards of access and safety for people with disabilities. He suggested that a higher level of accessibility will be needed without drivers to assist passengers.

Steinfeld discussed the challenges associated with access by people who use wheeled mobility devices. He noted that low-floor vehicles have reduced the need for assistance in boarding for this group. He suggested that a challenge for the industry is the development of very low-floor vehicles or kneeling features that reduce the ramp slope required for boarding to the point where all riders can manage without assistance. It is also important that the vehicles provide safe access for visually impaired passengers and older people using canes and walkers.

Steinfeld described the types of problems getting in and out of vehicles reported by older drivers. He noted that although the problems and solutions are known, many vehicle manufacturers have chosen to emphasize style over usability. He suggested that ride-hailing services could provide guidance to their drivers in the selection of cars based on this research.

Steinfeld discussed the importance of securing wheelchairs and scooters in vehicles and some of the issues associated with manual and automated systems. He suggested that the success of any AV technology that is covered by the Americans with Disabilities Act (ADA) such as shuttle buses and shared-van services depends on developing a system that can be used independently. Ideally, it would also allow passengers to face the front of the vehicle, as riders prefer to see where they are going.

Steinfeld described a usability test conducted by the IDEA Center comparing manual and automated securement systems for use in buses. The analysis included a nine-dimensional subjective assessment of universal design and observed time. Automated securement was better on the subjective assessment, which included perceived risk, embarrassment, and unwanted

attention as well as typical usability measures such as mental effort and efficient use. He noted that the results for observed time demonstrated that automated securement could reduce dwell time by several minutes in boarding and deboarding wheelchair users.

Steinfeld noted that securement is an issue for all vehicle passengers. He reported that fastening seat belts was the second most-common reported problem, at a rate of 30%, in a survey conducted by the IDEA Center of older users of passenger cars. He said that older people have difficulty seeing the attachment mechanism, pulling out the belt and swinging it around their body. He questioned who would be liable if an AV passenger does not use a seatbelt when the device is clearly difficult to use. He noted that the proper securement of children in an AV was another issue.

According to Steinfeld, vehicle interiors are also an important consideration with AVs. He report that IDEA Center research indicated that current buses are not adequately designed for easy use by people with disabilities. Wheelchair users have difficulty gaining easy access to securement areas. Visually impaired individuals have difficulty finding empty seats and there is no space to stow walking aids. He further noted that many people have difficulty with fare payment.

Steinfeld discussed another challenge related to communication with an AV, including effectively requesting destinations, obtaining customer assistance, and receiving help in emergencies. He noted that voice recognition systems still have difficulty dealing with strong accents. He commented that terminology and interpretation differences may impeded usability. He noted that systems relying only on voice recognition exclude use by people who cannot talk. He suggested that automatic monitoring may be needed to notify third parties if someone has a medical emergency while traveling in an AV.

Steinfeld described the Tiramisu app, developed at CMU. He noted that the research team included people with disabilities in the design and development process to insure that their needs incorporated. Features included in the app are information on when a bus is full and the ability to share experiences with others through pictures and text. He noted that a new version of the app is under development to address changes to the operating system.

In conclusion, Steinfeld said that practicing universal design can bring the benefits of AVs to all groups by adding value to products and services. He noted the importance of considering the diversity of riders starting at the conceptual stage and following through with constant improvements. He suggested that industry can get out ahead of regulators by adopting an inclusive approach voluntarily. He also noted that for businesses, this approach will improve the bottom line with better performance and broader markets.

The Future Is Autonomous Driving *But Are We on a Near-Term Collision Course? Revisiting the Topic*

BRYAN REIMER

*Massachusetts Institute of Technology AgeLab and
New England University Transportation Center*

Bryan Reimer questioned why traffic fatalities were increasing in an automotive ecosystem with deep investment in advanced driver assistance systems (ADAS) fueled by increasing automation. He noted that the preliminary estimates from the National Safety Council indicate that there were 40,200 motor vehicle deaths on U.S. roads in 2016. This number is a 6% increase over 2015, a 14% increase over 2014, and the highest in 9 years.

Reimer described automation as an evolving process. He noted that perhaps automatic transmissions were the “tipping point” in the influx of automation into the vehicle as they reduced driver’s operational workload, freeing resources to do other things, such as talk on a smartphone.

Reimer described the Advanced Vehicle Technology Consortium at MIT. The focus of the consortium is to collect cutting-edge data that objectively characterizes the behavioral and safety benefits of ADASs, higher levels of automation, and other in-vehicle technologies under real-use conditions. He noted that the outcomes focus on a data driven understanding of drivers’ utilization of advanced vehicle technologies (AVTs) and the development of data and analytic methods necessary for answering important questions about AVT.

Reimer described some of the research conducted by the consortium, including the MIT AVT Naturalistic Driving Study, which examined the Tesla autopilot system with 20 vehicles operating and collecting data in the Greater Boston area over an 18-month period. In addition, two Volvo S90 and two Range Rover Evogue vehicles were included in the test. Reimer noted that data from driving the 24 vehicles 138,188 mi are being analyzed, including 2.4 quadrillion video pixels. An updated synopsis of this work can be found at <http://hcai.mit.edu/mit-avt.pdf>.

Reimer discussed the experience with the two Volvo cars. He noted that the vehicles recently had been taken to the dealer, where unbeknownst to the study team, a software upgrade was installed. The upgrade was described to provide a few interface changes. He noted that in reality, however, the upgrade also changed the performance of the Volvo Pilot Assist package substantially and augmented the lane-departure warning system. He suggested that improving the performance of technologies such as Pilot Assist post-delivery could provide consumers with substantive benefits if changes improve system capabilities and user experience. However, if consumers don’t know about the changes they are less likely to benefit from them. He questioned if the use of the technology outside of the ODD was a foreseeable misuse or key experiential learning. He suggested that some form of georeferencing or structured learning may be pivotal to safety and effective transformation of the market place to leveraging the capabilities provided by these technologies.

Reimer discussed how an individual’s experience with technology impact their willingness to use and trust the technology. He stressed the need for driver to build trust, which takes times, since the future includes AVs will likely radically shift established mental models engineering in all the technological, political, and societal hooks needed to support trust is critical. He noted that recent data indicate consumer trust in the context of automation is declining.

Reimer discussed some of the data analyzed on the Naturalistic Driving Study. He noted that their dataset includes 16,000 transitions of control across 454 h of Tesla autopilot use. Of these

transitions, 42 involved the autopilot system communication to the driver to re-engage in the driving function. He reported that 12 of those situations involved the driver going over 90 mph, which is outside the domain of the autopilot system. Approximately 17 of the 42 situations could be classified as the AI systems needing assistance. He suggested that this early data suggests that drivers are finding ways to manage the technology.

Reimer suggested that the data is being used to begin to linking some of the established theory in automation to actual behavior and there are disconnects. The data can further provide insights into when a driver accepts a transition and when they regain full awareness. He also noted that the data can be used to examine different driver-use styles.

Reimer described using the naturalistic data to teach robots to drive. The approach included using end-to-end deep neural networks for perception and steering control. He suggested that a next step would be to teach AI systems to argue with each other and how the foundations of argument can be used to predict the likelihood of a transition of control from autopilot to the driver (human initiated) with over a 90% accuracy in a 6-s window. He suggested that these results indicate that drivers may be developing some level of awareness of the relationship between changes in the operational characteristics and systems capabilities in a way that is being mathematically quantified and projected through an AI system. He noted that the same methods could be used to functionally validate AI systems.

Reimer suggested that a future with AVs will include a growing level of “novice drivers” as our experience driving reduces and we learn less by doing and will not have the experience of drivers today to make the same decisions. He noted engineering ways to support a new novice driver may be necessary. This approach might include strategically engineering systems to coach and teach.

Reimer asked if driving is considered a privilege or a right. He noted that some people are predictably irrational and that it is plausible that some drivers will exploit the bounds of risk under many, if not all, driving contexts. He suggested that the challenge in the past has been engineering for the 90th-plus percentile, while the challenge in the future is designing to the outliers where the largest source of risk may be amplified.

In considering an autonomous future, Reimer suggested that human-centered technologies that consider people’s roles from the ground up would be pivotal. Further, safety will continue to be paramount. He noted that only the overlap of technology, policy, and human factors provide for the best potential of a successful transformation of how we live and move.

In closing, Reimer said that while the future will be autonomous, humans will continue to have a role for some time. As a result, he noted that most VMT in the coming years will involve a human at the wheel. He suggested that Level 2 systems introduce a number of use challenges, perhaps even more than at Level 3. Developers are focused on addressing potential issues with Level 3 through engineering, while leaving humans to deal with Level 2 concerns. Reimer reviewed three salient features that emerge when reported experiences are combined with quantitative data. These features are mode confusion, role confusion, and misplaced trust. He suggested that these features may be contributing to observed changes in safety. He said that investment in human-centered engineering throughout the automotive system is critical to a safe mobility future. He noted that improving communication with the driver is also critical. He further noted that developing host controller interface systems that provide individuals with a clear understanding of their roles on a moment-to-moment basis was important. A final need Reimer suggested was developing focused decision models that consider the state-of-the-vehicle and the human on a moment-to-moment basis may be critical for long-term success.

Drive Sweden

An Update on Swedish Automation Activities

JAN HELLÅKER
Drive Sweden

Jan Hellåker provided an update on Drive Sweden and other automation activities underway in Sweden. In keeping with commemorating the 20th Anniversary of the Automated Highway Systems Demo '97, Hellåker showed slides from the January 1989 Prometheus Board Member Meeting in Munich, Germany, where different advanced technology vehicles were displayed.

Hellåker described the diverse companies involved in the development and deployment of AVs and mobility services in Sweden. The three well known OEMs, Volvo Cars, Scania, and Volvo Trucks, are active in AV development. Newer companies include NEVS, LYNK & Co, and Einride. He also noted the new autonomous driving software company Zenuity, which is a joint venture between Volvo Cars and Autoliv.

Hellåker described the Drive Sweden Strategic Innovation Program. He noted that it is a government-sponsored, cross-functional collaboration platform aimed at designing the next-generation mobility system for people and goods based on connected, automated, and shared vehicles. He stressed the importance of shared AVs to avoid possible unintended consequences of automation.

Hellåker reported that the number of partners in Drive Sweden continues to increase. Currently, there are 60 partners involved in different Drive Sweden activities. He noted the importance of participation by government agencies, industries, research organizations, and other groups.

Hellåker described follow-up activities to the 2017 European Truck Platooning Challenge. Sweden4Platooning is a 3-year project, which includes Scania, Volvo Trucks, the Royal Institute of Technology, SICS Swedish ICT, DB Schenker AB, and the Swedish Transportation Administration. The main deliverables from the project include piloting a multi-brand CACC (longitudinal control) in a haulage company operation and demonstrating multi-brand truck platooning (lateral and longitudinal control) at a test track.

Hellåker discussed the response by Scania to a recent request for proposals (RFP) issued by the Singapore Ministry of Transport and the Port of Singapore for a drayage yard application of truck platooning to address a driver shortage. The RFP is for a four-truck platoon, with the lead truck operating at Level 0 and the three following trucks operating at Level 4. He showed a video of a three-truck platoon being tested as part of the project.

Hellåker showed a video of a Volvo pilot involving an automated refuse truck. Rather than getting in and out of the cab to collect the garbage receptacles, the driver walks behind the vehicle, which can safely navigate neighborhood streets without a driver.

Hellåker described the T-pod under development by Einride. The T-pod is an electric, driverless, or remotely controlled vehicle, set for prototype testing in late 2017. It has a cargo capacity of 15 standard pallets. The cross vehicle weight is 20 tons and the length is 7 m or 23 ft. The battery capacity is 200 kWh and it has a range of 200 km or 124 mi between charging. He noted that the T-pod will be fully driverless on highways, but can be remotely controlled, with one operator controlling multiple vehicles, in first- and last-mile applications. The commercial launch of the T-pod is planned by 2020.

Hellåker provided an update on NEVS. He noted that NEVS' vision is to shape mobility on product, service, and system levels. The focus is on EVs, mobility services, and city and society. In January 2017, NEVS was awarded one of the contracts to manufacture AVs in China. Their InMotion concept vehicle was exhibited at Consumer Electronics Show Asia. In addition, NEVS recently signed a memorandum of understanding with the Chinese company Didi Chuxing (Chinese Uber).

Hellåker discussed the Drive Me project, which focuses on self-driving cars for sustainable mobility. Drive Me involves 100 families commuting by self-driving Volvo XC90s on public roads in Gothenburg, Sweden. The pilot is scheduled to begin in the fourth quarter of 2017. It will involve highly automated driving at Level 4 on demand. There is not a safety driver and secondary tasks will be allowed by the operator. The highly automated driving will occur only on approximately 50 km of certified roads and there will be weather limitations on its use. He noted that the Drive Me partners include the Swedish Transport Administration, Chalmers, Volvo, the City of Gothenburg, the Lindholmen Science Park, and Autoliv.

Hellåker described the development of the Drive Sweden–Open Cloud environment to promote innovation, creativity, and information sharing. He reported that the first application was released recently. He discussed the AD Aware Traffic Control, which will be used to enable and disable the self-driving feature of the Drive Me cars on road segments based on real-time weather and incident data. He noted that including information on emergency vehicles approaching the Drive Me cars from behind is under development.

Hellåker described ASTAZERO, a new full-scale test facility for tomorrow's active safety and automation. The facility covers 2,000 acres and includes a rural road, a multilane road, a high-speed area, a four-block city area, and a proving ground. The facility also has its own, dedicated 4G/LTE cellular network, and a 5G network is under construction.

Hellåker described the living labs launched by Sweden's Prime Minister, Matti Vanhanen. The new program promotes the deployment of living labs for a wide range of new technologies. He noted that Drive Sweden had been appointed to organize two of these living labs. One project focuses on developing a framework for MaaS in Sweden. Project elements include examining business models, ticketing systems, legislation, and policy. Conducting and evaluating pilots and deployment are other project elements. Ongoing coordination and collaboration is also a key focus. He noted that it will include public transit, ridesharing, bike-sharing, and other modes.

Hellåker noted that the second project focuses on automated electric shared vehicles. Subprojects include a commercial shuttle between a subway station and a bus station in Stockholm using an EasyMile vehicle; automated docking and bus platooning using Volvo electric buses in Gothenburg; and shared shuttle services in Gothenburg. Cloud-connected traffic signals in Stockholm and Gothenburg represents another project. Still another project is building on the electric lock feature offered by Volvo Cars to simplify car-sharing. He noted that this application may require legislative changes to allow for the taxing of borrowing and paying for other people's vehicles. The final project addresses these types of issues through a policy lab.

In concluding, Hellåker noted that Drive Sweden is not just about driverless vehicles. It is a completely new approach to mobility. He suggested that a radical shift is underway, with entirely new mobility business models emerging to enable sustainable cities.

Korea's Autonomous Vehicle Policies

CHAE-GYU KIM

Bureau of Motor Vehicles Policy, Republic of Korea

Chae-gyu Kim discussed current conditions and achievements related to the AV development and deployment in Korea. He also described the Korean government's policy direction for developing and commercializing AVs.

Kim reported that 4.23 million vehicles were manufactured in Korea in 2016. Korea ranks sixth in the world among countries producing vehicles. Further, he noted that Korea has excellent information technology (IT) and communications infrastructure throughout the country. As a result, Korea has very good conditions for developing and deploying AVs.

Kim presented major achievements such as opening public roads for AV testing, building infrastructure, and providing various technical supports. He noted that the Korean government devised a plan to support commercialization of AVs in 2015. The government adopted a system that would permit the testing of AVs and initiated research and development for establishing safety standards. In 2016, the testing of AVs on public roads in the country was permitted. The testing of "no steering, no pedal" AVs was allowed in 2017. At the same time, the government began creating a 3D precision map to help the private sector in developing AV technology, and initiated Cooperative Intelligent Transportation Systems (C-ITS) trial service. Further, in 2016 research and development on safety standards and construction of the K-City test bed were initiated.

Kim discussed AV policies in Korea, including those focusing on commercializing AVs. He noted that under the vision of improving transport safety and creating new economic growth engines, Korea is actively supporting the commercialization of Level 3 AVs by the year 2020. He reported that the Korean government is developing a foundation for experimentation, conducting pilot projects, building needed infrastructure, and improving the system to support this vision.

Kim described the K-City test bed, which is under construction. K-City includes a variety of road and city conditions. It creates real-world situations for developing automated driving technology and improving safety. He noted that the high-speed road will be completed and open for use in the second half of 2017, and the entire facility is scheduled for operation in 2018. K-City will be available for private-sector use.

Kim reviewed the components of K-City, which is planned to simulate every situation that people can face in real life, including pedestrian crossings with traffic lights, fake buildings, bus stops, roundabouts, and a tunnel. In addition, for the development of vehicle-to-everything (V2X) technology, 4G and 5G communication will be installed. The facility will provide a repeated, yet safe testing environment.

Kim reported that in addition to K-City, the Korean government allows public access to a test road for AVs, utilizing an existing road. This 7.7-km road is equipped with a high-definition (HD) map, C-ITS, and other infrastructure improvements. Further, the Korean government designated two trial-operating areas at industrial complexes for AV testing.

Kim shared information on pilot projects in the planning stage, focusing on increasing the social acceptability on AVs and supporting technology development. During the 2018 PyeongChang Winter Olympic Games, automated driving will be demonstrated on a 200-km long

highway from Seoul to PyeongChang. A driverless shuttle service will also be provided around the Olympic Stadium. Further, a trial of a driverless shuttle will begin at the end of 2017 in Seoul.

Related to developing infrastructure for automated driving, Kim reported that the Korean government provides the public with a HD map, which contains 11 types of road information. The map is free and contains four lane-type indicators, four facility-type indicators, and three signal-type indicators. He noted that the map currently covers 1,305 km of major highways and urban roads in the country. By 2020, all highways and major cities are expected to be included in the map.

Kim described the development of HD GPS technology for AVs. He noted that the margin of error is less than 1 m. Trial service will begin near Seoul this year and the service will be expanded nationwide in 2019.

According to Kim, Korea is currently conducting C-ITS trial service as part of building V2X infrastructure. Real-time traffic monitoring through vehicle-to-infrastructure (V2I) communications is underway in some areas. It is anticipated that C-ITS will be developed on major highways by 2020.

Kim reported that Korea adopted a permission system for AV testing in early 2016. The system requires that a driver should be in the vehicle, an AV sign should be on the vehicle, and that insurance should be purchased. Further, vehicles must pass a pre-test drive that includes lane keeping and obstacle avoidance. Testing AVs on public roads except school zones and silver zones was approved in November 2016. The exceptional testing of “no steering, no pedal” vehicles was allowed in March 2017. He reported that the testing of 20 vehicles has been authorized to date, including those from Hyundai, Hyundai Mobis, Samsung Electronics, LG Electronics, and Seoul University.

Kim noted that Korea is conducting research and development on safety assessment technologies to establish safety standards for AVs. Safety standards for Level 3 will be developed by 2020. In addition, research is underway on an insurance system for AVs and liability issues in case of an accident. Further, AV recall and inspection systems are under review.

Kim described the Future Forum, which is a public–private consultative body established in 2016. It includes approximately 100 experts from various fields. He noted that the Future Forum was established after realizing that government alone cannot respond to major changes that AVs will bring to society.

Kim concluded by describing the different perspectives about the future and how quickly AVs will be in widespread use. He noted that Navigant Research predicted that 75% of new vehicles in 2035 would be equipped with automated driving technology. Kim suggested that although there are some differences in numbers, all forecasts predict that AVs will comprise the biggest share of the vehicle market.

Kim described a future of shared AVs summoned by using a smartphone, self-parking AVs, and driverless trucks to transport goods. He noted that the Korean government is helping the future arrive sooner and preparing for the change in lifestyles and society. He suggested that Korea is focusing on opening the future to AVs, and working with other governments, industries, and experts around the world to accelerate the beginning of the AV era.

Automated Vehicles in the United Kingdom

IAIN FORBES

Centre for Connected and Autonomous Vehicles, U.K. Department for Transport

Iain Forbes provided an update on AV activities in the United Kingdom (UK), focusing on the importance of being able to adapt to new information and changing conditions. The first example Forbes described related to regulatory reform to ensure the UK is a world leader in AV development and deployment. He noted that changes may be needed in regulations related to vehicle safety standards, driver training and licensing, insurance, crash investigation, criminal liability, taxi licensing, and many other measures. Forbes commented that reviewing current regulations and developing appropriate changes represents a major undertaking for the responsible agencies.

Forbes reported that motor vehicle insurance was one of the first areas to be examined. He noted that in the UK, the driver, rather than the vehicle is insured. This approach could potentially cause legal issues if there is a crash when a vehicle is operating in automated mode. He noted that establishing a framework to address these concerns seemed to be an appropriate step that would benefit manufacturers and the insurance industry.

Forbes described the process the UK went through to develop proposals for how an insurance system might work for Level 4 and Level 5 vehicles. The core of the proposal that the government originally consulted on was that when a vehicle was insured, a second insurance policy with product liability provisions that would apply to a vehicle operating in automated mode would also be purchased. He noted that the UK insurance industry provided two major comments during the consultation process. The first comment was that interfering with the product liability framework would open-up numerous issues. The second comment was that there was an easier method to achieve the desired policy objectives. This method was asking that the government force the insurance industry to pay claims.

The alternative proposal put forth by the insurance industry was that when an individual takes out an insurance policy on a vehicle that can drive itself without human oversight, part of that policy should also cover automated driving. The industry suggested that when there is a crash involving that vehicle operating in automated mode, the insurance company that issued the policy should have first instance liability. When an innocent party experiences harm, the insurance company issuing the policy is compelled to pay the claim under first-instance liability. In return, the proposal was that insurance companies would have strengthened rights to reclaim damages from the party that is ultimately responsible, which might be the manufacturer, the supplier, or another entity.

Forbes noted that this approach would not have any gaps, and claims would be paid quickly. He further noted that from a consumer perspective, the system would appear similar to the current system. Further, any complicated legal action would be between corporations, not individuals.

Forbes reported that a bill establishing this framework will be introduced in the UK Parliament in the near future. He suggested that additional changes in insurance laws may still be needed with AVs, but that this approach represents a good first step. He also noted that additional liability issues, especially those related to criminal liability, may also need to be addressed.

The second example of adapting an approach described by Forbes related to research and development. He noted that the UK government is making major investments jointly with industry in research and development to build capabilities in AVs, primarily through competitions set up to

encourage collaborative projects. He noted that many of the projects receiving funding during the first wave of investments are being tested.

Forbes reported that £35 million was set aside in 2016 for the third wave of projects that included a grand challenge focused on demonstrating Level 4 AVs in urban and interurban settings, zero-occupancy driving, and different operating environments. He noted that the original intent was to select one winning team, but that the quality and the range of the responses was overwhelming. Responses included convoying six automated cars between London and Oxford, last-mile passenger service using AVs in London, and a long-distance self-driving EV.

Forbes reported that due to the quality of the proposals, the funding amount was doubled and multiple projects were selected. He highlighted the diversity of teams, which included global automotive companies, new technology companies, universities, and other groups. Forbes said that a fourth wave of competitive projects would be initiated soon.

The third example of adapting to new information Forbes described addressed test beds. He noted that the testing of AVs on any public road is allowed in the UK. Building on this advantage, testing environments have been established to accelerate the development of automated technologies. Forbes reported that a focus in 2016 was identifying cities and towns that were interested in becoming test beds. He noted that feedback from industry before launching the approach resulted in a change in direction. He said that industry feedback included three main points. The first point was that the right capabilities were needed in three different environments to accelerate AV development and deployment. These environments are public roads, controlled environments adapted to the task of validating advanced systems that will operate in real-life driving conditions, and virtual capabilities to rapidly develop and validate concepts.

The second point made by industry was that the UK already had some highly competitive assets for AV testing and demonstrations, but that these assets could be integrated and strengthened for more robust and unique application. Examples of these test facilities cited by Forbes included the Millbrook Vehicle Proving Grounds, Nissan's European Technical Center, Cranfield University's test sites, and the Transport System Catapult. Other facilities in London included the UK Smart Mobility Lab in Greenwich, the GATEway trial, the connector corridor from London to Dover, and the Volvo arterial road project. He noted that there are also facilities around Oxford, Bristol, and the Midlands.

Forbes stressed the close proximity of all these assets. He noted that within 70 mi of Oxford there are three of the world's top universities, the UK's automotive heartlands, London (Europe's only mega city), six of the 10 Formula One Racing teams, the major AV trials in the UK, a world class cyber security cluster, and a range of cutting-edge simulators and established proving grounds. Industry stressed the need to pull these assets together more efficiently.

The third point made by industry was that targeted government investment could upgrade and integrate these environments to create a one-stop shop for AV development. In response to these suggestions, the UK government announced £100 million for CAV testing infrastructure in November 2017. Forbes reported that the funds, which will be matched by industry, will ensure that the UK has comprehensive and globally competitive AV testing capabilities. He noted that the first £55 million competition closes soon and that there will be a second phase later in the year. He noted that this approach was much more comprehensive than originally outlined due to input from industry.

In closing, Forbes stressed the importance of flexibility and the ability to respond to new information in developing and deploying AVs. He noted that the program in the UK has benefited from the ability to modify direction in response to feedback from industry and other groups.

Strategic Innovation Promotion-Automated Driving Systems for Universal Service

An Update on Japanese Initiatives for Automated Driving

YOICHI SUGIMOTO

*Integrated Control System Development Division
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Yoichi Sugimoto discussed the Cross-Ministerial Strategic Innovation Promotion (SIP) Program in Japan. He noted that the SIP was initiated in 2014 focusing on science, technology, and innovation through basic research, application research, and commercialization. It also focuses on enhancing cross-ministerial cooperation. Automated driving systems for universal service (adus) is one of 11 research themes in SIP.

Sugimoto described the Japanese Government promotion framework related to ITS and automated driving systems. The Cabinet Secretariat, IT Strategic Headquarters, and the Cabinet Office of the Council for Science, Technology, and Innovation provide overall direction and coordination. The National Police Agency is responsible for road traffic safety. The Ministry of Internal Affairs and Communication is responsible for info-communication technology for ITS. The Ministry of Economy, Trade, and Industry promotes the automobile industry. The Ministry of Land, Infrastructure, Transport, and Tourism includes the road bureau deployment of road infrastructure and the road transport bureau safety standards for automobiles.

Sugimoto reviewed the SIP goals, which include ensuring safety and traffic jam reduction on the roadway system. Other goals focus on realizing automated driving systems and advanced next-generation public bus service for vulnerable individuals.

Sugimoto highlighted the different technologies used with automated driving systems. He noted that priority research and development areas include dynamic maps, cybersecurity, human-machine interface (HMI), reducing pedestrian fatalities, and next-generation transportation. He further noted that these activities are being conducted in cooperation with industry and academia.

Sugimoto described the development of the dynamic map, including establishing the Dynamic Map Planning Co., Ltd. The dynamic map provides an advanced traffic information database for all vehicles, as well as a precise map for automated driving vehicles. He noted that the map includes dynamic information, semidynamic information, semistatic information, and static information. He stressed the importance of scalability, ease of updating, security, and reasonable cost in developing and maintaining the map. Sugimoto reviewed the public-private partnership for collecting, generating, processing, and using the dynamic map database.

Sugimoto described the data flow in the dynamic map, including data collection, generation, processing, and use. He summarized cybersecurity research and development activities underway, including examining common models of advanced driving for threat analysis, developing validation and evaluation methods and criteria, and assessing certificate validation of V2X communication. He highlighted the development of a threat analysis tool.

Examples of HMI research and development discussed by Sugimoto were investigating the effects of system information on driver behavior and investigating the effects of driver behavior in the transition from autonomous to hands-on modes. Another research area is investigating effective ways to functionalize AVs to be communicative with other road users.

Sugimoto described research and development activities focusing on reducing collisions between vehicles and pedestrians and bicyclists. Two efforts he noted included the use of V2P communication and infrastructure radar with V2I communication.

Sugimoto discussed elements of the Advanced Rapid Transit (ART) system, including the ART information center. He noted that ART focuses on safe, convenient, and seamless transit services. ART elements include a public transportation priority system, real-time information on congestion and transit services, dynamic connection guidance, and remote diagnostics.

Sugimoto summarized a large-scale FOT (free on truck) that will be initiated in the fall of 2017 to activate the research and development program. Elements of the FOT include the dynamic map, HMI, social acceptability promotion events, next-generation urban transportation, pedestrian accident reduction, and information security. He noted that the FOT will enhance international cooperation and harmonization. It will include the OEMs, suppliers, ministries, universities, and research organizations. Sugimoto further noted that the FOT will use a section of expressway, arterial roads in the Tokyo waterfront area, and at test course at the Japan Automotive Research Institute.

Sugimoto highlighted elements of the FOT. The dynamic map component of the FOT includes validating the 3D high-resolution digital map data and validating data collection and distribution methods. It also includes verifying the utilization of semi-dynamic information. HMI elements include collecting and analyzing driver state data, defining driving readiness status, and verifying HMI methods and devices. A cybersecurity example highlighted by Sugimoto was validating the evaluation method and inspecting the defense functions of ADV.

Sugimoto commented that, beginning in the 1880s, automobiles have shaped lives and development patterns. He noted that regulations, guidelines, and standards were developed over time to provide safe travel. He suggested that a similar situation exists today with the development of automated driving and the need for a common base platform to promote safety, harmonization, and standardization.

In closing, Sugimoto described international cooperation activities. He noted that experts have been assigned to focus areas, including the dynamic map, CVs, human factors, impact assessments, the next generation of public transport, and security. These efforts are coordinated with the formal EU–U.S.–Japan cooperation initiative and the International Organization for Standardization (ISO). Sugimoto reported that the annual SIP-adus Workshops provide opportunities for international cooperation and coordination. The 2016 SIP-adus Workshop was held November 15–17 in Tokyo. It included 425 participants from 17 countries. He noted that the 2017 SIP-adus Workshop will include demonstrations along with sessions.

Automated Vehicle Initiatives *European Union*

GEREON MEYER

VDI/VDE Innovation + Technik GmbH

Gereon Meyer described the framework for stakeholder discussions and strategic thinking associated with European policies on AVs, especially in the research and development domain. He highlighted the organization of the European Commission (EC) on policy, regulation, and innovation for connected and automated driving. He noted the different EC directorates, programs, and roundtables focusing on CAV research and development, as well as activities in the member states.

Meyer reported that these activities focus on the common objective of accelerating the deployment of a cooperative, connected, and automated mobility. He described the common responsibility and shared leadership approach involving public and private stakeholders. Meyer discussed the development of European Technology Platform Roadmaps on different topics, which include stakeholder consultation and discussions with industry, academia, and member states.

Meyer highlighted the European Road Transport Research Advisory Council's Automated Driving Roadmap, which includes plans for connected and automated passenger, freight, and urban mobility. The European Roadmap Smart Systems for Automated Driving was a second example highlighted by Meyer. He noted that this roadmap, which is currently being updated, focuses on technology needs for evolutionary and revolutionary CAV developments.

Meyer described the Strategic Transport Research and Innovation Agenda, which is a comprehensive top-down, EC strategy covering all transport modes. He noted that it includes Horizon 2020 actions for connected and automated road transport.

Meyer also described bottom-up approaches that are user centric. He highlighted Mobility4EU, which involves diverse stakeholders examining societal factors associated with AVs. He noted that the bottom-up initiative is cocreating a multimodal action plan with users.

Meyer reported that the roadmaps are being used to develop the work programs of the Horizon 2020 framework, which is the major framework for research funding in Europe. He reviewed some of the research topics from previous project calls and noted that the 2018–2019 project calls were expected to be published soon.

Meyer highlighted the diverse EU-funded connected and automated driving projects. He noted that the first project was initiated in 2005. Projects from the 2016 calls have begun and 2017 projects are in second applications stage. Examples of topics in the 2017 call address connectivity, automated driving pilots, infrastructure needs for the coexisting AVs and conventional vehicles, and coordinating deployments in Europe.

Meyer discussed the first EU connected and automated driving conference, which was held in Brussels, Belgium, in April 2017. The conference was organized by the EU-funded projects Coordination of Automated Road Transport Deployment for Europe and Safe Connected Automation Road Transport. He noted that the conference included an integrated program covering EU policy and innovation dimensions. The breakout session he helped organize examined the synergies between electrification, automation, and sharing. Breakout session participants discussed that new usage models will tighten the links between the technology paths.

In closing, Meyer noted that he and Sven Beiker were the co-editors of the book, *Road Vehicle Automation 4*, published from the 2016 AVS (<http://www.springer.com/us/book/9783319609331>). He said that the book is available in 300 libraries worldwide and that work has been initiated on Road Vehicle Automation 5 highlighting elements of the 2017 AVS.

U.S. Department of Energy's Focus on Energy-Efficient Mobility Systems

DAVID ANDERSON

Vehicle Technologies Office, U.S. Department of Energy

David Anderson described the new Energy Efficient Mobility Systems (EEMS) Program in the U.S. DOE's Vehicle Technology Office, which was launched in January 2017. He highlighted recent trends influencing transportation, the five EEMS focus areas, and advanced research and development activities underway at the Vehicle Technology Office.

Anderson noted that mobility is foundational to the American way of life, as well as a large part of the country's energy economy. He reported that transportation is the second largest expense for U.S. households. Further, transportation accounts for approximately 70% of total U.S. petroleum usage, with on-road vehicles accounting for 85% of the transportation-sector petroleum usage.

Anderson discussed converging trends that are shaping mobility. He highlighted trends focusing on population growth, demographics, and technology. The population of the United States is expected to grow by around 70 million people in the next 30 years, with 75% of the population concentrated in 11 megaregions. Related to demographic trends, Anderson noted that Americans are living longer. By 2045, the number of Americans over 65 years of age is projected to increase by 77%. About one-third of this age group have a disability that limits mobility.

With approximately 73 million Americans between 18 to 34 years of age, Anderson noted a second demographic trend relating to the Millennial generation. This age group appears to be less interested in vehicle ownership and more interested in shared mobility services.

The third trend focuses on technology. Examples Anderson cited included the integration of connected and automated technologies, the introduction of shared service platforms, and advancements in energy storage technology. Anderson also noted the impact that information technology is having on individuals' lives, enabled by the availability of big data coupled with faster computer processing speeds at decreasing cost.

Anderson suggested that these trends are causing a fundamental disruption in transportation. He noted that industry is leading the introduction of disruptive business models and technologies based on consumer demand. Examples he cited included CAV, ride-hailing, car-sharing, new powertrains, and new modes of transportation. He reported that the DOE is interested in better understanding if this disruption will lead to new energy efficiency opportunities, identifying the potential risks to energy use and ways to overcome them, and investing in the most promising innovation levers for a sustainable energy future.

Anderson described previous work examining the energy impacts of different AV and shared services scenarios conducted by some of the national laboratories. He noted that this bounding study concluded that the impacts of CAVs could range from a 60% decrease in energy consumption to a 200% increase in energy consumption in 2050. He suggested that more research was needed to better understand these potential outcomes and to achieve a maximum-mobility and minimum-energy future.

Anderson reported that the Vehicle Technologies Office has expanded its traditional focus on vehicles and components to the transportation system and network level. He noted that the office develops advanced transportation technologies that improve energy efficiency,

increase domestic energy security, reduce operating cost for consumers and business, and improve the global competitiveness of the U.S. economy. Programs in this office focus on electrification, materials technology, advance combustion systems and fuels, and deployment. The new EEMS program joins this portfolio.

Anderson described elements of the EEMS program, including the Systems and Modeling for Accelerated Research Transportation (SMART) Mobility Lab Consortium, high-performance computing/Big Data analytics initiative, advanced research and development projects, and living labs. He also noted that core Vehicle Technologies Office evaluation and simulation tools are also available to support these activities.

Anderson discussed the SMART Mobility Lab Consortium, which focuses on creating new knowledge and understanding about the energy implications and opportunities from future mobility. He described the five SMART Mobility pillars: CAVs, mobility decision science, urban science, advanced fueling infrastructure, and multimodal transportation. The CAV pillar focuses on the energy, technology, and usage implications of connected and autonomous technologies and how these systems will operate in the real world. The critical levers to promote “eco-CAV” solutions are also being explored.

Anderson reviewed the mobility decision science pillar, which examines the transportation energy impacts of potential lifestyle trajectories, how consumers and companies make travel decisions in the short, medium, and long term, and available mechanisms to influence consumer decisions.

The urban science pillar focuses on how SMART-enabled mobility might affect the urban traveler in terms of VMT, congestion, vehicle ownership, and MaaS. It also addresses the long-term impacts on the urban built environment and the energy impacts of optimized signal management and automated mobility districts.

Advanced fueling infrastructure is the fourth pillar. Topics of interest in this pillar include infrastructure requirements to support future mobility systems, next-generation fueling–charging infrastructure enabling energy-efficient transportation, and identifying the costs and benefits of infrastructure investments.

The fifth pillar focuses on multimodal transportation. Topics of interest in this pillar include the potential energy benefits of reduced modal interface barriers, the interaction between mass transit and TNCs, and the opportunities that evolving household spending and commodity flow bring for freight logistics.

Anderson highlighted examples of advanced research and development projects focusing on hardware devices, software solutions, control systems, advanced sensors, and powertrain components. One project underway at the University of Michigan is developing an adaptive spatiotemporal intersection control system that reduces fuel use by approximately 15%, while improving travel time.

Anderson also highlighted the recent announcement of three new research projects awarded through a recent Vehicle Technologies Office Funding Opportunity. One new project at Clemson University will focus on boosting the energy efficiency of heterogeneous CAV fleets via anticipative and cooperative vehicle guidance. Project elements include developing anticipative–collaborative traffic and vehicle control algorithms to achieve a 10% energy savings, conducting high-fidelity transportation and vehicle simulation to quantify energy benefits, and validating the results at an on-track vehicle-in-the-loop testbed.

A second project at UC Riverside will evaluate energy efficiency opportunities from CAVs coupled with shared mobility in California. The project includes conducting real-world

CAV data collection and analysis, modeling impacts on energy intensity and modal activity, and constructing a statewide energy inventory.

The third project highlighted, with the Virginia Polytechnic Institute and State University, will develop an ECO-Cooperative Automated Control System. Project tasks include developing network-level vehicle-routing and speed-harmonization algorithms, developing vehicle-level energy management algorithms, and integrating network and vehicle algorithms to demonstrate a 20% energy savings while improving the level of service.

In concluding, Anderson noted that major disruptions are occurring in transportation and that CAVs are coming. He further noted that CAVs and shared mobility services have dramatic implications for energy use and that the DOE must understand these energy impacts and develop the knowledge to enable energy efficiency in transportation to promote a maximum-mobility, minimum-energy future.

Update on U.S. Department of Transportation Automation Programs

KEVIN DOPART

*Intelligent Transportation Systems, Joint Program Office
U.S. Department of Transportation*

Kevin Dopart provided an update on the automation policies, programs, plans, and research and development underway at the U.S. DOT. He noted that the AV technology efforts are coordinated across multiple U.S. DOT agencies, including the Intelligent Transportation Systems Joint Program Office (ITS JPO), NHTSA, FHWA, FMCSA, FTA, and the Maritime Administration (MARAD).

Dopart reviewed the NHTSA Federal Automated Vehicles Policy, which was released September 20, 2016. The comment period, which included two public workshops, closed November 22, 2016. He noted that NHTSA released Policy FAQs/Clarifications on January 2017. He also noted that U.S. DOT Secretary Chao has said that new guidance will be issued in next few months that will support industry innovation and encourage open communication with the public and with stakeholders. It will also make department processes more nimble to help match the pace of private-sector innovation and will encourage new entrants and ideas that deliver safer vehicles. He commented that NHTSA driving automation research is focusing on electric control systems safety, system performance, human factors, and cybersecurity.

Dopart reported that FHWA is developing an agencywide Vision Statement to establish its role in supporting the integration of AV technologies onto the nation's roadways. He noted that AV technologies might affect the planning, design, construction, maintenance, and operation of the nation's roadway infrastructure. The Vision discusses agencywide goals and guiding principles for FHWA with respect to AV technologies.

Dopart highlighted FHWA's cooperative automation research focused on developing cooperative driving automation system applications. Research on light vehicle and truck platooning includes CACC via V2V. Signalized intersection approach and departure research is using GlidePath via Vehicle-to-Infrastructure (V2I). Automated traffic flow optimization research includes speed harmonization via V2I. Proof of concept research is focusing on lane changing, merging, and weaving operations. He also noted that FHWA is evaluating the impacts of automated driving technology on the transportation planning process.

Dopart discussed the development of an FTA Automation Research Plan. The FTA Office of Research, Demonstration, and Innovation is developing the 5-year plan for FTA research and deployment. The plan focuses on bus transit automation, which is defined broadly to include low-speed shuttles and other rubber-wheeled vehicles. Key inputs to the plan include the Vehicle Assist and Automation program, Mobility on Demand (MOD) Sandbox, stakeholder perspectives, use case analyses, and benefit-cost analyses. He noted that the plan will be available September 2017.

Dopart highlighted research underway at the FTA. Knowledge transfer focuses on informing internal and external stakeholders about state of the practice and research in progress. Technology transferability is assessing the transferability of light-duty and commercial vehicle sensors and technologies to transit applications. Policy reviews are identifying and analyzing

federal, state, and local policies relevant to transit automation and providing recommendations for needed revisions or development of new policies.

Dopart described the FMCSA automated commercial vehicle activities. The agency is gathering information on issues relating to the design, development, testing, and deployment of HACVs. He noted that FMCSA seeks information on how to ensure that federal safety regulations provide appropriate standards for the safe operation of HACVs from design and development through testing and deployment. Public comments are being collected through July 17. Additional considerations being explored by FMCSA include commercial driver licensing, hours of service, and inspection, repair, and maintenance.

Dopart summarized the MARAD automation activities. The Low-Speed Automated Truck Queue at Ports and Warehouses is a joint project with FMSCA and the ITS JPO. The project is exploring the application of automation to low-speed commercial vehicle operations at port terminals and warehouses. He noted that the project includes a review of related studies and papers, surveys of industry and technology stakeholders, and a technology scan of existing or near-term enabling technologies. The project also includes estimating the costs and safety benefits of low-speed automated truck applications at ports.

Dopart summarized examples of automation research underway at the ITS JPO. Technical research includes assessing applications for improving system safety, developing impact assessments, and evaluating new data collection and sharing models. Program and policy support activities include strategic planning and roadmap development, as well as modal policy support and coordination. Stakeholder engagement activities include supporting professional capacity building efforts, facilitating international coordination, and assisting with the low-speed automated shuttle information sharing working group.

Breakout Summaries

BREAKOUT SESSION 1: RESEARCH TO EXAMINE BEHAVIORAL RESPONSES TO AUTOMATED VEHICLES

Yoram Shiftan, Technion University

Session Focus

The goal of this session was to identify research needs and develop research approaches, both quantitative and qualitative, for gaining deep insight on 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.

Summary of Discussion

- Participants discussed how the VOT might change with AVs for different segments of the population and how these changes in VOT would affect various choice dimensions.
- Participants discussed vehicle use and ownership, including personalized AVs and ride sharing AVs. Participants explored the potential early adopters of AV and sharing services, the different stages of automation, and the factors affecting vehicle sharing.
- Participants discussed the possible influence of AVs on induced activities, destination choices and opportunities, and alternative time use.
- Participants explored how land use and location choices might change with AVs and the relationship of VOT to other factors.
- Participants discussed how AVs might change travel behavior, including children traveling alone in AVs, changes in the VOT, multitasking while traveling, and destination and residential location decisions. The benefits and limitations of stated preference surveys and other methods of obtaining information on possible impacts were discussed by participants.

Suggested Action Items

- Participants discussed the need to explore using combinations of different research approaches to answer the complex questions associated with AV adoption and use.
- Participants identified the need to collect and analyze longitudinal data from existing shared services and AV use. This analysis could follow changes in perception and attitudes and compare areas with different development patterns and AV penetration rates. Longitudinal data from shared mobility services could also be examined.
- Participants discussed that coordinating surveys with field experiments would be beneficial.

- Participants suggested that research exploring methods to build upon existing survey instruments and leveraging technology to collect data was needed. Using smartphone apps and new technology could be considered in the study.
- Participants identified needed research to improve stated-preference survey methods, including the use of VR, gaming, and movies.
- Participants suggested that more naturalistic studies would be beneficial.
- Participants discussed the need to collect and analyze qualitative data using interviews and focus groups to better understand people's motives and goals. The need to collect more psychometric indicators was also highlighted by participants.
- Participants noted the importance of long-term learning and suggested that developing standard questions to include in various surveys and field experiments would assist in this effort.

BREAKOUT SESSION 2.1: JUDGING A CAR BY ITS COVER AND THE HUMAN FACTORS IMPLICATIONS FOR AUTOMATED VEHICLE EXTERNAL COMMUNICATION

Ruth Madigan, University of Leeds

Session Focus

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 movement of a vehicle. Uncertainty exists as to whether HAVs 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.

Summary of Discussion

- Participants in the session discussed how and when HAVs should communicate with road users while in motion, when stopped, and while in transition.
- Participants discussed the complexities associated with designing systems to support communication between AVs and other road users, including unmanned research vehicles and other drivers.
- Relevant human factors design heuristics were discussed by participants.

Suggested Action Items

- Participants suggested the need for research focusing on two-way communication between vehicles and other road users. The research could explore how vehicles can sense or detect the intent of other road users. Participants discussed that one-way communication, where a vehicle displays its intent, but does not recognize the behavior of other road users, is not enough.
- Another research need identified by participants focused on the amount and content that is displayed to external road users and if it should also be displayed to passengers and operators, including specialized communications for HAVs used as taxis.

- An additional research topic discussed by participants was examining the potential for an alert or communication methods to extend an event, rather than resolve it. Topics to examine in this research included identifying likely situations that do not require the alerts and obtaining a better understanding of when to use vehicle movements, such as merging on a highway, as a communication method.

BREAKOUT SESSION 2.2: AUTOMATED VEHICLE CHALLENGES: HOW CAN HUMAN FACTORS RESEARCH HELP INFORM DESIGNERS, ROAD USERS, AND POLICY MAKERS?

Chris Schwarz, University of Iowa National Advanced Driving Simulator

Session Focus

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.

Summary of Discussion

- Participants discussed that driver education will become more important in the future and there will be more of a gap in the needs of different segments of the population and in the way OEMs provide information.
- Participants and panelists suggested that customer acceptance is still an open question. “How safe do AVs need to be for public acceptance” is a key question.
- Participants noted that people are creative and will find ways to misuse any automated driving system.
- Participants also noted that people are not necessarily good judges of relative risks.
- Some panelists suggested that the reported 94% driver error in crashes may be hiding some vehicle and environmental issues.

Suggested Action Items

- Participants suggested that research developing and adopting new education methods would be beneficial. Approaches such as “Ok Ford, how do I ...?” could be included in the research.
- Participants discussed the need to close the gap between reality (the real capabilities of a system) and marketing. Research on this topic was suggested as beneficial.
- Participants noted that OEMs can learn from aviation and other industries and that an ongoing focus should be learning from other industry sectors.
- Participants suggested that research was needed on how to raise drivers’ awareness of a system’s limitations.
- Other research needs suggested by participants were exploring if manual override should always be available and assessing the risk of skill degradation and how to mitigate.

- Participants noted that these topics will be developed into new research needs statements.

BREAKOUT SESSION 3: ENABLING TECHNOLOGIES FOR AUTOMATED VEHICLES

James Misener, Qualcomm

Session Focus

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.

Summary of Discussion

- Participants discussed the technologies associated with different AV applications. It was noted that the technology lexicon is sometimes different among the various groups involved in AVs. Developing a common lexicon was suggested as beneficial by participants.
- Participants discussed advances in crowdsourced localization techniques and emerging lightweight cryptographic techniques. The different approaches to HD maps were discussed. It was noted that vehicle industry suppliers, industry standards, government initiatives, and road striping inventiveness often use different approaches, resolution, and latency.
- A few of the topics that were not discussed extensively included back office technologies and infrastructure technologies, that government agencies may be considering.

Suggested Action Items

- Participants identified the need to better understand how system complexity and infrastructure system preservation treatments might add new layers of complexity to various systems approach. Research examining this issue was noted as beneficial by participants.
- Participants suggested that research was needed examining the cyber issues associated with sensor security and with software updates. Participants noted that these elements are very different in their risk portfolios and processes.
- Participants discussed options for breakout sessions at the 2018 AVS. One option identified was developing two sessions—one on onboard technologies and one on technologies that depend on infrastructure. Maintaining one session with a systems perspective was also discussed.

BREAKOUT SESSION 4: AN AUTOMATED VEHICLE CRASHES: WHAT HAPPENS NEXT?

Karlynn Stanley, RAND Corporation

Session Focus

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.

Summary Discussion

- Similar to the current situation, participants suggested that liability would continue to be debated between plaintiff and defense attorneys.
- Participants also suggested that law enforcement investigations would not change much, at least initially.
- The insurance industry perspective was that AVs are not viewed as an existing crisis, but rather as an opportunity to continue creating products that help people and companies manage risk.

Suggested Action Items

- Participants suggested that research on the types and amount of data that should be captured in crashes involving AVs would be beneficial.
- A related research topic identified by participants was examining the sources and integration methods of critical data on infrastructure, weather, and road conditions.
- Cybersecurity issues were also discussed by participants. It was suggested that cybersecurity measures should be given more attention, including firewalls and domain separation.

BREAKOUT SESSION 5: PUBLIC TRANSPORT AND SHARED MOBILITY

Gary Hsueh, Arup

Session Focus

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.

Summary of Discussion

- Participants discussed that research in transit automation, MOD, and shared AVs was accelerating. Examples cited included research projects sponsored by NCHRP, the FTA Transit Automation Roadmap, and the FTA MOD Sandbox. European research examples were also highlighted.
- Participants discussed that while shared AVs offer major benefits to society, they probably will not happen on their own due to potential issues associated with zero-occupant vehicles, labor, equity, VMT, data availability, permitting, and personal preferences.
- The experience with pilot projects at Pinellas, AC Transit, Bestmile, and Gomentum Station were discussed. Some of the lessons learned included setting reasonable expectations, not being afraid to fail, getting technology in front of users and regulators to change perceptions and to facilitate adoption, initiating pilots, and learning through an interactive process. It was noted that pilots have been initiated by both public and private entities.
- There was also discussion on policy needs at the early and interim stages of testing and deployment.
- Participants discussed the need for strong multi-group partnerships to make AV pilots, test deployments, and implementations work.

Suggested Action Items

- Participants discussed possible follow-up projects in NCHRP 20-102(02) related to laws, regulations, and the future of AV transit.
- Participants suggested ongoing tracking of the FTA's Transit Automation Roadmap and the MOD Sandbox projects.
- Research exploring the impact on transit during the interim period of mixed use and how to reach a fully automated state was suggested by participants.
- Exploring how cities and transit agencies can take on expanded roles as mobility managers and brokers, working in partnership with mobility providers was identified as a potentially helpful research project by participants.
- Another research topic identified by participants was investigating the roles and mechanisms for new and evolving mobility services to address societal issues, such as access and equity, the ADA, Title 6, and environmental justice.
- Research to better understand thresholds of acceptable risks for cities and transit agencies was identified as an additional helpful research.
- Participants stressed the benefits of continuing to share lessons learned from transit and shared AV deployments.

BREAKOUT SESSION 6: TRUCKING AUTOMATION: KEY DEPLOYMENT SCENARIOS

Johan Engström, Virginia Tech Transportation Institute

Session Focus

This two-part breakout session focused on key challenges and opportunities associated with the deployment

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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.

Summary of Discussion

- Participants discussed that the technology needed for truck automation applications and truck platooning was available, but that deployment was the real challenge.
- The key drivers supporting truck platooning identified during the session were improved fuel economy, productivity, and safety. The shortage of truck drivers was also noted by participants as an important factor. It was suggested AVs and truck platooning provide opportunities to improve drivers' jobs and to retain and attract good drivers.
- Challenges discussed by participants included defining the benefits and the ROIs from automated trucking specific to the type of operation, addressing the diversity of operations, and considering multidimensional problems.
- Speakers and participants discussed that one major key to truck automation deployment was understanding the customers' operations.
- Participants discussed that Level 1 platooning was very close to being market ready and that it would provide the opportunity for other applications.
- Public-sector participants expressed interest in exploring managed and dedicated lanes for automated trucks.

Suggested Action Items

Participants identified the following items as key to the successful deployment of automated trucking.

- Stepwise deployment and validation in real operations.
- Develop safety assurances by collecting field data in combination with track testing and simulation.
- Establish cooperation between stakeholders and develop new strategic partnerships.
- Develop and implement educational campaigns and demonstrations to establish public awareness and trust of automated driving technologies.
- Develop harmonized regulations associated with truck automation among states.

BREAKOUT SESSION 8: URBANISM NEXT WORKSHOP: AUTOMATED VEHICLES' EFFECTS ON URBAN DEVELOPMENT

Gerry Tierney, Perkins+Will

Session Focus

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.

Summary of Discussion

- The first development pattern discussed by participants was a pre-World War II streetcar suburb. The neighborhood has a typical grid development, is walkable, and is well served by light rail and bus. Retail stores serve the neighborhood, with emerging artisan shops serving a regional market. Potential changes due to AVs suggested by participants included parking reductions of up to 90% in a shared AV environment, which will create opportunities for infill development. This approach is also compatible with enhanced transit and shared mobility services environment. Some of the freed-up parking lots could be repurposed to neighborhood parks and a street diet could enhance walkability and bicycling. Regional serving “artisanal” retail would be well served by shared AV and enhanced transit. Overall, participants suggested that the future outlook for this type of neighborhood was good with AVs.
- The second development pattern was a post-war big-box strip mall. The existing conditions included lots of surface parking, low levels of transit service, and poor conditions for walking and biking. Further, the big-box retail is under pressure from e-commerce.
- In discussing the future impacts from AVs on the big-box strip mall, participants suggested that AV-induced parking demand reductions, combined with e-commerce, would provide opportunities for infill development, and that increased density would create opportunities for enhanced transit services. Participants also suggested that a vacated and reduced retail footprint will require catalyst tenants to prevent blight. Further, cities will need to find alternative tax sources to counteract the reduction in sales tax revenues from increases in e-commerce. Participants highlighted that there would be opportunities for street diets to enhance walkability and bike use in the area. Overall, participants suggested a mixed future outlook for the area, with some good and some bad due to e-commerce impacts.
- Participants discussed that maintaining an overall focus on community goals is important. The deployment of technologies needs to address improving the quality of life, ensuring social equity, taking care of all residents’ needs, and creating opportunities for commerce. Consideration of emerging technologies within the context of these goals and filters should be encouraged.
- Participants suggested that the potential benefits to be derived from an AV environment need to be identified in a holistic manner and directed toward the benefit of all. While the transportation efficiencies are important, consideration also needs to be given to the downstream impacts of AV development and deployment, which will be “game changers.” The potential exists to fundamentally change many aspects of how people shop and work.

- Participants discussed that it is important to consider AV development and deployment in a holistic manner. Helping the technology community understand the importance of the nontechnical issues, and the importance of translating possible implications to the public was discussed. Obtaining a better understanding of how people will interact with these vehicles is needed.
- Participants stressed that planners and policy makers need to understand who the stakeholders are and engage them in a meaningful manner. Bringing a broader discussion of the possible secondary impacts would be beneficial, including considering social equity and spatial justice issues.

Suggested Action Items

- Participants supported encouraging TRB and AUVSI to continue this dialogue at the 2018 AVS and other appropriate conferences.
- Participants suggested possible research ideas under umbrella scenarios, such as the EU's Mobility4EU initiative or the U.S. DOE's Urban Structures Research Area.
- Participants encouraged local policy makers and planners to engage in the dialogue to promote broadening coordination across agencies at the municipal, state, and national levels.

BREAKOUT SESSION 9: EFFECTS OF VEHICLE AUTOMATION ON ENERGY USAGE AND EMISSIONS

Avi Mersky, CMU

Session Focus

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 systemwide models, the impacts of CACC, the impacts of vehicle sharing, the impacts of other technologies, and policy implications and impacts.

Summary of Discussion

- Participants suggested that VMT would likely increase in response to AV technology, assuming private vehicle ownership. It was further suggested that energy efficiency and vehicle emissions intensity would likely decrease, but that energy consumption and vehicle emissions may increase in aggregate.
- Participants noted that the usefulness of the gasoline taxes would decrease as funding sources, assuming that most AVs are electric.
- Participants discussed that CACC and platooning systems would theoretically improve fuel economy and lane capacity, but that it was not known how human drivers would actually respond to such systems in mixed traffic.
- Participants suggested that current fuel economy regulations do not capture autonomous technology well and that safety technology cannot be considered for off-cycle credits.

Suggested Action Items

- Participants discussed how to weigh the different goals of absolute reductions in vehicle emissions and energy versus reductions in intensity.
- Participants supported the ongoing discussion of alternatives to the current gasoline tax, including VMT tax options.
- Participants identified research needed to examine the potential of gaming CACC and platooning systems in mixed-traffic environments and methods to prevent possible attacks.
- Participants reported the need for research investigating methods for regulating fuel economy of AVs, including methods for evaluating the potential external benefits of AVs, and if external benefits should be included in fuel economy standards.

BREAKOUT SESSION 10: DATA SHARING MODELS AND POLICY

Shawn Kimmel, Booz Allen Hamilton

Session Focus

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. The following questions helped focus the decision during the session.

- What are the value exchanges between various public and private entities that incentivize sharing?
- What types, formats, and granularity of data are needed to achieve the desired benefits?
- How can public agencies best prepare data infrastructure and policy to be ready for AVs?
- How can AV data be shared while protecting proprietary and liability concerns?
- What data standards are needed to support data sharing, and what is the role of the public and private sectors in developing and enforcing these standards?

Summary of Discussion

- Participants discussed safety and performance data from test cases, performance reporting, and post-crash reconstruction.
- Participants discussed infrastructure and operations data, including road closures, weather, incidents, and emergency response.
- Participants discussed challenges with determining what data is actually needed, the specific level of data needed to answer questions, and the fidelity and value of the data being shared. The need to distinguish between various types of data, including cooperative data (work zone, incident, etc.) and competitive data (user experience data, etc.), was also discussed by participants.

- Participants discussed possible challenges with establishing partnerships among private and public entities, and reaching agreement on data ownership, data sharing, and monitoring data.
- Participants also discussed opportunities with data sharing, including finding champions and encouraging support for data-sharing activities.
- Participants discussed the maturity of public agencies in terms of their ability to share data with the private sector.
- Participants discussed that the public's expectations are changing related to how data is used, liability, and privacy. Participants also discussed that the federal government has a role in data scaling and system architecture development.

Suggested Action Items

- Participants suggested that research developing and providing guidance on the roles and responsibilities of different public- and private-sector groups in collecting, maintaining, and sharing specific data elements would be beneficial. The research could further examine what data elements are competitive and what data elements are cooperative.
- Participants supported research to provide guidance to public agencies on how to inventory and format data, and how to assess data integrity.
- Participants supported providing guidance on standardizing certain data elements, especially road closures, incidents, emergency vehicles, and weather.
- Participants identified the need to develop a roadmap for public agencies to approach the private sector on the type of information that could benefit roadway maintenance, and operations, and how to develop partnerships for obtaining and using data.

BREAKOUT SESSION 11: ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING FOR AUTOMATED VEHICLES

Hao Liu, PATH, Institute of Transportation Studies, University of California, Berkeley

Session Focus

Autonomous driving relies on in-vehicle computers that emulate the functions of a human brain in making informed decisions. Such systems 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. The speakers focused how their work was aligned with the main theme of the session. This was the first breakout session sponsored by the TRB standing committee on Artificial Intelligence and Advanced Computing Applications.

Summary of Discussion

- Participants discussed that AI and ML are useful for a broad spectrum of applications, including traffic flow prediction, travel behavior estimations, and isolated intersection and

corridor operations. Additional AI and ML applications discussed were vehicle powertrain control optimization and developing hardware and software platforms for AVs.

- Participants discussed that all these applications have great potential for improving traffic safety and efficiency.
- Participants discussed the trade-off among computational efficiency, solutions quality, and robustness with different AI and ML applications.

Suggested Action Items

- One research topic identified by participants focused on investigating a methodology framework for algorithm calibration. Elements suggested for inclusion in the research were considering real-world data versus simulation data, developing performance metrics, and identifying acceptance criteria.
- A second research topic suggested by participants was improving algorithm performance for specific applications, including short-term traffic flow prediction and travel behavior estimations.
- A third research topic identified by participants was exploring AI use as a safer driver and actuator of traffic management strategies.

BREAKOUT SESSION 12: TESTING CONNECTED AND AUTOMATED VEHICLES: ACCELERATING INNOVATION, INTEGRATION, DEPLOYMENT, AND SHARING RESULTS

Cynthia Jones, Ohio Department of Transportation

Session Focus

This session represented the first time a breakout group on CAV testing was conducted as part of the AVS. The session included updates on CAV proving grounds, a panel and discussion on roles and partnerships in CAV testing, a panel and workshop on next steps in collaboration, and wrap-up comments.

Summary of Discussion

- Participants supported that CAV testing is necessary, that it is a global concern, and that it is all encompassing. Participants viewed testing as critical for implementation of CAVs.
- Participants stressed that testing cannot be conducted by only one company or team, or at one site or simulation. Multiple venues are needed with different geographies, climates, and conditions. Participants noted that U.S. DOT, states, cities, OEMs, universities, transit agencies, and many other groups have roles to play in testing.
- Participants discussed the great potential in testing collaboration and the willingness of different groups to partner.
- Participants recognized that the strong interest in testing is a critical aspect of CAVs.

Suggested Action Items

- Participants discussed the need to focus on the unifying goal of safety as a way of bringing diverse perspectives together.
- Participants discussed the different expertise and facilities that are available at the different proving grounds and test sites. Participants suggested that it would be beneficial to define the roles and capabilities of different groups to facilitate collaboration.
- Participants supported outlining opportunities for sharing information among groups and test sites, including integrated data exchanges, near-crash data, and crash data.
- Participants developed a draft Global Test Bed Collaboration Plan during part of the breakout session. The draft plan will be available after they symposium.

BREAKOUT SESSION 13: CHALLENGES AND OPPORTUNITIES FOR THE INTERSECTION OF VULNERABLE ROAD USERS AND AUTOMATED VEHICLES

Justin Owens, Virginia Tech Transportation Institute

Session Focus

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.

Summary of Discussion

- Participants discussed the importance of raising awareness among OEMs, policy makers, and other groups about the potential negative and positive impacts of AVs on VRUs.
- Participants discussed possible safety issues and human factors concerns for VRUs with AVs.
- Participants discussed learning from current crash data to identify possible safety impacts to VRUs from AVs.
- Participants discussed the unique characteristics of the time period when a mixed fleet (AVs and legacy vehicles) will be in operation and safety concerns for VRUs.

Suggested Action Items

- Participants suggested using current crash scenarios to predict conflict types and data needs for AV–VRU interactions.
- Participants identified that research was needed to explore methods of AV detection of pedestrians and bicycles, and determining ways to improve upon the current state of the art. The research could examine how V2X communications can assist in detection, and the potential benefits and limitations of this technology from behavioral and technical standpoints.

- Participants noted that research should be conducted into the technical, human factors, and cultural issues surrounding communication of intent among AVs and VRUs, including how is right-of-way determined and communicated.
- Exploring designs that can respond to cultural and geographical differences in pedestrian and bicycle behavior concerning right-of-way and social customs was another research topic identified by participants.
- Participants suggested that research should be conducted to optimize the passing behavior, both decision and distance, of AVs around VRUs, particularly bicyclists.
- Another research topic identified by participants was exploring the use of simulators to test interactions between AVs and a variety of VRUs, including older adults, children, and people with a range of disabilities.
- Participants discussed the need for research to develop and test messages needed to educate VRUs about AV technology, including best practices to communicate the benefits of AV to a broad audience.
- Participants identified the need for research addressing legal and ethical issues, including when can AVs break the law, liability in the case of crash, and the legal responsibility in crashes involving non-AV vehicles, AVs, and VRUs.
- Participants identified a number of research needs related to data. Research topics included exploring driver assistance technologies that currently work well, exploring standardization of data, and building a database consisting of AV and VRU interactions, crashes, and lessons learned.

BREAKOUT SESSION 14: ENHANCING THE VALIDITY OF TRAFFIC FLOW MODELS WITH EMERGING DATA

Meng Wang, Delft University of Technology

Session Focus

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

Summary of Discussion

- Participants discussed that data from the existing field tests may not fulfill the need for traffic flow models.
- Speakers and participants noted that estimating the impacts of AVs requires more accurate descriptions and models of human driver behavior.
- Participants discussed that while it is not likely that industry will use the AV algorithms developed by traffic modelers, the insights of CAVs on traffic flow may provide lessons for industry as they develop AVs.
- It was suggested by some participants that achieving traffic flow benefits at low AV market penetration rates would be challenging but rewarding.

Suggested Action Items

- Participants supported developing partnerships with governments to facilitate data collection opportunities.
- Participants identified the need to provide inputs from the traffic flow modeling perspective in the design phase of field experiments.
- Participants supported encouraging funding allocations for common databases as data collection is expensive.
- Participants identified the need to educate the public on the benefits of AVs as traffic control actuators.
- Participants suggested that research to improve the validity of baseline driver models would be beneficial.

BREAKOUT SESSION 15: CONNECTED AND AUTOMATED VEHICLE SCENARIOS FOR HIGH-SPEED, CONTROLLED-ACCESS FACILITIES

Chris Poe, Texas A&M Transportation Institute

Session Focus

This session focused on scenario planning for CAVs on freeways and managed lanes. The session was developed jointly by the TRB Freeway Operations, ITS, Managed Lanes, Highway Capacity and Quality of Service, and Traffic Control Device committees. 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.

Summary of Discussion

- Participants discussed that CAVs should offer improvements in safety and throughput, and reductions in traffic congestion on high-speed, controlled-access facilities.
- Participants suggested that it was important to consider the impact of CAVs on the entire transportation network, as CAVs will need to use other roadways to access the high-speed facilities.
- The numerous opportunities for data sharing were discussed by participants, along with the challenges associated with sharing data among the many private and public entities involved in CAVs.
- The need for simulation tools to assess possible impacts and operations was identified by participants.
- Participants discussed different options for when and where vehicle platoons involving trucks, buses, passenger vehicles, and mixed fleets could operate.
- The potential for CAVs to change the way work zones are designed and operated was discussed by participants.

- Participants explored options for integrating CAVs into the operational spectrum for managed lanes.

Suggested Action Items

- Participants suggested that no significant changes in infrastructure geometry are needed in the near term for CAVs, but that opportunities exist for better planning, road markings, and signing.
- Participants supported continuing the dialogue among OEMs, suppliers, and infrastructure owners and operators.
- Two synthesis topics were identified during the session. One topic focused on summarizing current CAV research, pilot projects, and deployments. A second topic addressed summarizing the status of multistate truck platooning pilots and projects.
- The five sponsoring committees will also use the input from the discussions to develop research needs statements.

BREAKOUT SESSION 16: AFTERMARKET SYSTEMS: ADVANCED DRIVER ASSISTANCE SYSTEMS RELATED

Jim Misener, Qualcomm Technologies Incorporated

Session Focus

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.

Summary of Discussion

- Participants discussed that data collection is a key hidden value beneath the aftermarket device's basic value proposition, but that challenges remain for OEMs in the cost of data collection, liability for data, and finding effective ways to monetize data. The possibility of providing a free data plan in exchange for vehicle data was discussed by participants.
- Some participants noted that cameras are sensors with the highest growth, partly driven by regulations and by multifunctional applications (even if not perfect solution) with software updates. It was suggested by some participants that V2X is the only other sensor that could probably be integrated as an aftermarket device. V2X, unlike sensors, provides information, not just data.
- Participants discussed aftermarket systems that can predict crashes and prevent them (such as Waycare and Banjo start-ups), are "faster to dashboard," and can bring the latest in wireless connectivity. The path to market for these devices may be through government (local DOTs) or fleets to address local problems with fast solutions. Insurers may give reductions to fleets for ADAS devices, but not for private users with personal automobiles.

- Participants discussed if aftermarket systems should be standalone or embedded with vehicle's infotainment system as a refinement. Both approaches are viable, but standalone aftermarket devices are much more prevalent.
- Participants discussed that AI should learn from the best drivers (20% of driver population), not just "obey rules of the road," e.g., crossing the middle line to pass a cyclist. AI should take advantage of all the available capabilities that humans do not have.
- Participants discussed that DSRC in smartphones is challenged because Wi-Fi radio has to be 10 times more powerful.
- Participants discussed that the current wireless infrastructure is ill-suited to transport 1 TB/vehicle per day from connected vehicles and that there may be a need for Wi-Fi and DSRC in certain locations to minimize cellular usage, as most data can be delay-tolerant. Telecom operators may be willing to install DSRC in roadside units (RSUs) to offset traffic loads. V2V mesh software updates can be 10 times cheaper than using 4G. It was noted that most aftermarket devices are single function and rely on cellular (dictating only small amounts of data) and not upgradeable.

Suggested Action Items

- Participants identified the need to define if there is there an aftermarket for safety systems and how effective these systems can be when fitted in post-production.
- Participants suggested the need to examine the optimization of wireless networks based on probable data uploading or downloading requirements.
- Participants discussed if cellular technology could play a role in safety and how and when will it be tested side-by-side with DSRC. Participants also discussed if the aftermarket will prove to be an effective path to market for DSRC.
- Participants noted that aftermarket devices need to be multifunctional, multinetwork-capable, and upgradeable. It was further noted that business and technical challenges need to be addressed with data collection. A critical point of discussion was the volume of data that will be shared in the future and the role direct communications will play, whether using cellular or DSRC. Exploring what the automotive industry can learn from the fleet sector in terms of required fitment of collision avoidance systems was suggested as beneficial.
- It was noted that at the core of all of these solutions is the extraction of data via cellular or DSRC to enable the aggregation, interpretation, and sharing of data between vehicles—both in real time and as when convenient to lower costs.
- Possible research topics related to the adoption of V2X were discussed. Researching, developing, and distributing a model for the market uptake of V2X, assuming it is being installed exclusively in new cars, should include variables for government mandates for completeness around the world. Researching, developing, and distributing a model for the market uptake of V2X, assuming a variety of aftermarket V2X devices are made available, should include variables such as a government mandate requiring various levels of capability, direct cost allocation (consumer only, insurance company trade-off with consumer, and shared cost with traffic authority). Other factors to consider include the level of professional installation required versus capability versus cost (assumed higher cost and difficulty leads to lower adoption rate), the factors that will draw consumers to desire such devices, and possible factors that will be negative for aftermarket adoption.

- An additional research project discussed by participants was developing a detailed model of the impact of aftermarket safety devices (ASD) at different levels of absorption and the potential impacts of different sets of applications. For example, Intersection Motion Assist (blind corner) apps may have a different impact than forward collision alert (FCA) and electronic emergency brake light (EEBL).

BREAKOUT SESSION 17: SAFETY ASSURANCE

Hermann Winner, Technische Universität Darmstadt

Session Focus

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

Summary of Discussion

- Participants discussed that databases with relevant traffic scenarios are a key component for the safety assurance validation and development process.
 - Participants noted that it is not always possible to evaluate the AV software by physical cases only. Participants further noted that simulation plays a crucial role on different scales.
 - Participants discussed that virtual software-defined networking (SDN) for physical resource management is an innovative way of addressing these problems.
 - Participants suggested that safety validation should include a structured combination of three methodologies: simulation, proving ground testing, and onroad testing.
 - Participants noted that cybersecurity is a concern that needs to be progressively addressed.
 - Participants suggested that cooperation among stakeholders would be beneficial, and discussed possible ways to encourage and implement sharing among diverse groups.
 - Participants noted that customers' perception of benefits and consumers understanding of functionalities sometimes are not aligned with reality.
 - Participants discussed the need for a full verification when a new functional component is added. Avoiding a full verification when lower levels of automation have been verified was suggested by participants.
 - Participants noted that over-the-air upgrades may present some challenges.

Suggested Action Items

- Participants suggested a follow-up effort focusing on encouraging the interesting and grand challenges of SAAVs with young researchers.
- Participants stressed the importance of maintaining the momentum from the breakout session and the interested parties and stakeholders, so that continuing research and developments can benefit the greater community.

- Participants suggested a follow-up activity of promoting the sharing of driving scenarios and databases among the various stakeholders.
- Participants discussed the need for researchers and stakeholders to face these challenges. Communicating this need to diverse stakeholder groups was suggested by participants as a possible follow-up activity.
- Participants suggested the ongoing follow-up activity of continuing to obtain a better understanding of the challenges associated with AV safety assurance.
- Participants discussed the importance of maintaining the momentum of the current gathering of interested parties and stakeholders.

BREAKOUT SESSION 18: READING THE ROAD AHEAD: INFRASTRUCTURE READINESS

Scott Koznicki, Dubai Office of Transport Group

Session Focus

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.

Summary of Discussion

- Participants discussed that consistency and logical applications may be more important than compliance.
- Speakers and participants discussed that machine vision manufacturers expect use of the best, well-established practices with traffic control devices.
- Participants discussed that shortfalls exist in machine vision capabilities relative to more complex environments.
- Participants discussed that the development of a readiness framework goes beyond the level of automation or operating domain. Participants further suggested that readiness ratings will require multicriteria topology and uniform assessment practices.

Suggested Action Items

- Participants discussed that most agency personnel and consultants do not have an extensive understanding of machine vision systems. As a result, participants suggested that it was important to connect machine vision experts with transportation system management and operations engineers, traffic design engineers, and traffic control device manufacturers.
- Participants noted the need to identify shortcomings on both sides and collaborate on filling identified gaps. Planning a “Sensors 101” plenary panel for the 2018 AVS was suggested by participants.

- Participants suggested that research using the human factors primacy triangle to better understand driving tasks would be beneficial. The research could examine driver assistance devices as a means of countering human shortfalls. It was also suggested that delineation was more important than signing, except regulatory signs in low-information environments.
- Participants noted that 2009 was a long time ago and that the MUTCD (23 CFR 655) is not timely enough to set standards for machine vision applications. Developing new consistency criteria that focus on critical devices was supported by participants to address these deficiencies.
- Participants suggested that convening an independent consortium to develop readiness criteria, assessment methodologies, and rating and needs identification databases would be beneficial. It was noted that these items are key in determining the minimum required investments. Items to consider with this approach included identifying possible risks of “stamp of approval” in tort liability and identifying key components of hand-off needs and locations for various domains and regimes.

BREAKOUT SESSION 19: SHARK TANK: CHANGE IS COMING—WHO WILL SURVIVE?

Richard Mudge, Compass Transportation and Technology

Session Focus

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.

Summary of Discussion

- End of congestion. The first topic addressed by the panel was that CAVs would eliminate traffic congestion. Comments addressing this topic included the potential for large net economic benefits from reduced congestion levels and the potential for induced demand to increase VMT. It was suggested that the per-mile costs of AVs will be quite low, which will discourage private car ownership. A reservation system for individual trips could be used, with shared vehicles representing an important part of the solution.
- Freight revolution. The second topic focused on driverless trucks, which should allow considering freight options other than the standard truck size. Public safety was noted as an important issue. It was suggested that Amazon’s purchase of Whole Foods has major implications for urban freight.
- State and local agencies fade away. The third topic focused on the changing roles and responsibilities of state and local transportation agencies with AVs. Discussion topics included the changing roles for transit agencies with shared mobility services, the potential for contracting out services to result in private monopolies, and methods to guarantee service equity.
- No one owns cars. The fourth topic examined a major change away from individual’s owning vehicles to individuals sharing vehicles. Panelists and participants suggested that this type of change would be a function of land use and density. It might occur over the next 10 years

in city centers, over the next 25 years in suburbs, and even longer in rural areas. It was also suggested that this change would result in decreases in both VMT and person-miles traveled.

Suggested Action Items

- Participants supported continuing this type of session at the 2018 AVS. The open discussion of the topics by both the speakers and the panelists was noted as very beneficial by participants.
- Possible research topics identified by speakers, panelists, and participants during the session included examining the potential impacts of shared AVs and mobility services on VMT and public transit, exploring the evolving roles of transportation agencies, and assessing the impacts of automated trucks on public safety.

BREAKOUT SESSION 20: MAKING AUTOMATION WORK FOR CITIES

Siegfried Rupprecht, Rupprecht Consult

Session Focus

This session examined the status of automation in cities and metropolitan areas in the United States and Europe. The focus provided 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.

Summary of Discussion

- Participants discussed the importance of clear, widely supported policy goals that focus on the expected contributions and benefits of CAVs. It was noted that there appear to be similar goals among the larger cities focusing on safety, inclusion and access, and mobility.
- Participants discussed the need to create strong multistakeholder partnerships (public–public, public–private, etc.) Concerns were voiced that in some cities there is a lot of OEM testing, but no partnerships.
- Participants discussed the need to support walking, biking, and using transit. Equity concerns were also noted, with AVs not just for the wealthy.
- Participants suggested that there is no automation without connectivity.
- Participants discussed how should cities start, should they still invest in large buses and infrastructure improvements? It was noted that automation is a new topic for most cities; it needs joint efforts and the introduction of AVs will be slow. Obtaining the ownership of stakeholders and involving citizens is important. A major challenge is how to organize the involvement process.
- Participants discussed that approaches to stakeholder participation are very different, including social experiment and a technical approach. Participants noted that both approaches should coexist and should learn from each other.

- Participants discussed the need for cities to work closely with OEMs while they are looking for new markets and are interested in demonstrations in cities, be clear about policy goals, create trust, manage cities expectations, and keep an eye on the business case.

Suggested Action Items

- Participants suggested that developing automation readiness criteria for cities—incorporating the items discussed—would be beneficial.
- Participants noted that considering impact assessments from the beginning was needed. Developing guidelines for these impact assessments, including identifying clear performance measures for automated services/providers, was suggested as a research need by participants.
 - Clarifying the expectations on users’ cross-brand experiences or a uniform local brand was also suggested as important.
 - Participants discussed the importance of involving other municipal services (e.g., waste collection, street cleaning, snowplowing) and suggested that space management would be a key future challenge.
 - Participants noted the importance of considering the wider context of automation and innovation ensuring that automation is part of an innovation cycle, including learning, was noted as important, as was synchronizing the technology and policy transitions the new mobility paradigm in cities.
 - Participants noted the importance considering the wider transition landscape (MaaS, digital infrastructure, energy, etc.) and how supporting ecosystems can contribute (e.g., planning, labor relations, procurement).
 - Participants supported the continuation of engaging in learning and exchange activities, including international dialogues.

BREAKOUT SESSION 21: CONNECTED AND AUTOMATED VEHICLES IN TRAFFIC SIGNAL SYSTEMS

Young-Jun Moon, The Korea Transport Institute

Session Focus

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 CAV. 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 intersection of roadways. This session included nine presentations and the follow-up discussion.

Summary of Discussion

Participants discussed the following research questions associated with a two dimensional diagram of connectivity and automation.

- How to improve intersection control from the current practice by using CAV data?

- How to consider different demand levels, multimodal, infrastructure adaptation?
- How will fleet vehicles from shared mobility companies impact the traffic control?
- How will public agencies benefit from CAV activity?

Suggested Action Items

- Participants discussed the intelligence level of traffic control and defining an intelligence level of traffic control, similar to vehicle automation level defined by SAE. For example:

- Level 0: Fixed-time control (time-of-day).
- Level 1: Existing adaptive control system (e.g., SCOOT).
- Level 2: Detector-free signal control (smarter coordinator at the intersection).

More research to develop this concept was suggested by participants.

- Related to the connectivity and automation diagram, participants identified needed research on intersection intelligence-level changes with levels of connectivity and automation.
- Participants discussed the need for research associated with performance measures, noting that the objective function of traffic control may change with AVs. A current performance measure is intersection delay for vehicles. This measure may need to change to personalized delay. Possible new objectives and performance measures may focus on sustainability, energy, and risk minimization. Further, participants suggested that research on objectives and performance measures, which may be needed during the transition period, would be beneficial.
- Participants discussed that CAVs will provide continuous data. Research is needed to examine how trajectory data will replace conventional detection and if loop detectors will disappear. Research on how navigation data from Google, Tomtom, and other providers can be used in this setting was also identified as needed by participants.
- Participants supported encouraging shared mobility companies to share their data with the research community.
- Participants discussed that controllability should increase over time with changes to higher automation levels. The experience with Didi (in China), related to observability, was discussed. It was noted that only 3% of vehicles are Didi vehicles. Without infrastructure detectors and using only trajectory data, better signal timing plans can be generated. Participants suggested that there is a need to examine this experience, including the frequency of signal retiming and closed loop control instead of open loop control.
- Participants suggested that research examining the impact of different CAV penetration rates would be beneficial. It was suggested that changes will not be linear and that people will be conservative when the penetration rate is low.
- Another research topic identified by participants was a theoretical analysis of capacity increases with the increase in automation level. Traditional traffic control has fixed capacity with a focus on how to better allocate the capacity and remove inefficiency. Traffic control with CAVs should increase capacity, allowing more cars to move through an intersection. The research should include pedestrians who are usually not considered when studying signal control with CAVs, and the potential for increased capacity to increase demand, which may result in more congestion.
- Other research topics identified by participants included examining customer acceptance of CAVs, the impact of vehicle technologies on CAVs, and centralized versus decentralized traffic control algorithms.

BREAKOUT SESSION 22: LEGAL AND POLICY APPROACHES: FINDING THE RIGHT BALANCE ON LEGISLATING FOR AUTOMATED VEHICLES

Baruch Feigenbaum, Reason Foundation

Session Focus

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.

Summary of Discussion

- Participants noted that AVs are a positive development for safety, mobility, and convenience.
- Participants suggested that data should be collected in a structured, systematic matter.
- The need for high-level system management, new taxonomy roads (urban/rural), and scenario planning for options to enhance legislation and policy and that development was identified by participants.
- Participants suggested that legislation should serve as building blocks, overregulation should be avoided, as technology is advancing faster than the ability to legislate.
- Participants noted the need to balance the intent in developing AVs with the need to serve the public.
- Participants noted that relationships among policymakers, experts, law enforcement, and the public were important in advancing appropriate policies, legislation, and guidelines.

Suggested Action Items

- Participants noted the continuing need to provide better education for policymakers and the public. It was further noted that this is the third year for a policy breakout session, and that the need for better education has been a priority each year. Participants discussed that targeting resources to develop enhanced information and conduct outreach efforts would be beneficial.
- Another follow-up activity suggested by participants was providing an integrated process for policymakers to work with each other across government levels and through public-private working groups. It was noted that each group is studying issues individually with very little coordination across efforts.

- Participants suggested the need to look to the future, but focus on the near-term. It was noted that there is a tendency to focus on SAE Level 5 AVs, but that intermediate levels of AVs offer advantages as well.

BREAKOUT SESSION 23: CONNECTED AUTOMATED VEHICLE EARLY DEPLOYMENT ALTERNATIVES

Dale Thompson, Federal Highway Administration

Session Focus

This session examined 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.

Summary of Discussion

- The FHWA CAV research activities and tests were presented. The CACC and light vehicle platooning with longitudinal control concept has been proven feasible. Next steps include examining platooning stability, performance character, light and heavy vehicle streams, and infrastructure impacts. The signalized intersection eco-approach and departure, GlidePath, has been tested with a single vehicle at one intersection. The tests showed a 22% fuel economy improvement with partial automation versus 7% with manual driving. The next steps include using two vehicles at two intersections. The speed harmonization research includes modeling streams of vehicles receiving speed control recommendations from a transportation management center (TMC). The results showed reduced congestion and the potential to double vehicle capacity.
 - The PATH performance analysis of CACC impacts on freeway traffic through simulation was presented and discussed.
 - Three common themes from the discussion were connected and automation issues, early deployment issues, and cybersecurity risks.

Suggested Action Items

- Participants discussed needed research to begin to address real-world deployment issues.
 - Research topics and next steps with CACC and light vehicle platooning (longitudinal control) identified by participants included examining ingress–egress merging, infrastructure impact, and premature damage. Other topics to examine in the research were the optimum size of platoons, gaps and headways, optimum vehicle performance criteria to engage in platooning, and handshakes between vehicles. Examining the potential for the early transition using managed lanes or dedicated lanes, and exploring lane change issues and visibility limitations of the lead vehicle were also suggested.
 - Participants identified additional research on the signalized intersection approach and departure (GlidePath) project. Topics included examining mixed traffic impacts, connected and

nonconnected vehicles in a traffic stream, and vehicle performance characteristic algorithms for each vehicle.

- Possible research needs associated with speed harmonization identified by participants were exploring methods to obtain operating agency engagement early in field testing and analyzing benefits that justify investments.

- Cybersecurity risks also came up as a research topic during the discussion.

Participants suggested that examining infrastructure vulnerability and vulnerable vectors into vehicles as messages/requests go to vehicles from the TMC.

BREAKOUT SESSION 24: AUTOMATED VEHICLES FOR PEOPLE WITH DISABILITIES

Sudharson Sundararajan, Booz Allen Hamilton

Session Focus

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.

Summary Discussion

- Participants discussed the needs and challenges of different disabilities. The design of AVs should consider integrating solutions to address the needs and challenges of different disabilities. Participants discussed the need to develop a conceptual framework to inventory, analyze, and develop requirements to address these differences and challenges.

- Participants suggested that it was also important to consider the interaction of AVs with the surrounding built environment and pedestrians in the development of AV design criteria.

- Some speakers noted that OEMs are interested in providing mobility solutions to all user groups—including the disabled community—that have social impacts.

- Participants discussed the importance of data formats and standardization (performance and outcome related) when considering an information data-based universal design.

- Speakers and participants discussed policy and regulatory barriers that affect the outcome of services, such as paratransit service reservations within 24 h and serve provision within a 2-h window.

- Speakers and participants discussed the challenges pedestrians face interacting with vehicular traffic and the importance of bidirectional communication with AVs, especially during the transition phase where AVs and non-AVs are in the traffic mix.

Suggested Action Items

- Participants suggested research that examines methods to integrate automation solutions into human service transportation for people with disabilities and older adults in both urban and rural areas.

- Participants noted that individuals with disabilities have similar needs as other groups. As a result, AV design that accommodates the varied needs and challenges of all groups is important and brings a feeling of inclusion to all groups.
- Participants discussed that data in silos has limited value. Industry methods to integrate data sources into associated needs and services (e.g., connected citizens, caregivers, safety alternatives) was identified by participants as a needed research area.
- Participants noted that technology is changing at a very rapid pace and the different industries need to work together to develop integrated solutions in planning and design stages. Research to identify integrated approaches and to use the approaches was suggested by participants as a follow-up action item.
- Participants suggested the need for research exploring collaborative efforts to review, analyze, and develop or make recommendations for updated sets of standards, policies, and regulatory frameworks for universal accessibility for use by all elements of the transportation industry.

BREAKOUT SESSION 25: ETHICAL AND SOCIAL IMPLICATIONS

Steven Shladover, University of California PATH Program

Session Focus

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 the NHTSA's guideline on ethical considerations in vehicle automation.

Summary Discussion

- Participants discussed that while there has been a lot of attention on the ethics of AVs crashing, there are more pressing challenges with ethical issues associated with AVs in routine driving and vehicle design.
- Participants discussed that ethics are relevant in noncrash events, such as decelerating at a stop sign in a way that is considerate to following vehicles.
- Participants also discussed that ethics are important in noncrash-risk scenarios through social justice and fairness, such as ensuring that high-resolution maps are created for both wealthy and poor neighborhoods.
- Participants discussed the difficulty of showing compliance with the NHTSA guideline on ethical considerations. Topics that were raised by participants included the right level of transparency and demonstrating that the approach used was developed consciously and intentionally.
- Participants discussed what possible rights drivers or passengers might have in customizing a vehicle's ethics settings. It was noted that respecting customer preference on ethics is challenging. The possible ethics of taxi drivers were discussed by participants. Participants suggested that the experiences from early automated ridesharing pilots may provide useful insights into this topic.

Suggested Action Items

- Participants identified the need for more research examining the limits of utilitarian reasoning in AV ethics.
- Participants suggested encouraging AV developers to comply with NHTSA ethics guidelines, and other future requirements, by demonstrating competency by hiring experts and integrating the expert into the entire design process.
- Participants identified needed research examining the early automated TNC deployments for customers' revealed preferences for ethical vehicle behavior such as speed, smooth decelerating, passing distance, and following distance.
- Participants suggested that research considering the ethics of AVs beyond crash events focus on considering both routine driving that generates risk, as well as societal, psychological, and economic impacts was needed.

TABLE 1 List of Breakout Sessions

Breakout Session	Appendix with Detailed Summary
Breakout 1: Research To Examine Behavioral Responses to AVs	Appendix A
Breakout 2.1: Judging a Car by its Cover: Human Factors Implications for Automated Vehicle External Communication	Appendix B
Breakout 2.2: Automated Vehicle Challenges: How can Human Factors Research Help Inform Designers, Road Users, and Policy Makers?	Appendix C
Breakout 3: Enabling Technologies for Automated Vehicles	Appendix D
Breakout 4: An Automated Vehicle Crashes: What Happens Next?	Appendix E
Breakout 5: Public Transport and Shared Mobility	Appendix F
Breakout 6: Trucking Automation: Key Deployment Scenarios	Appendix G
Breakout 7: Enterprise Solutions Series (not summarized)	
Breakout 8: Urbanism Next Workshop: Automated Vehicles' Effects on Urban Development	Appendix H
Breakout 9: Effects of Vehicle Automation on Energy Usage and Emissions	Appendix I
Breakout 10: Data Sharing Models and Policy	Appendix J
Breakout 11: Artificial Intelligence and Machine Learning for Automated Vehicles: Exploring Tools, Algorithms, and Emerging Issues	Appendix K
Breakout 12: Testing Connected and Automated Vehicles: Accelerating Innovation, Integration, Deployment and Sharing Results	Appendix L
Breakout 13: Challenges and Opportunities for the Intersection of Vulnerable Road Users and AVs	Appendix M
Breakout 14: Enhancing the Validity of Traffic Flow Models with Emerging Data	Appendix N
Breakout 15: CAV Scenarios for High-Speed, Controlled Access Facilities	Appendix O
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Breakout 24: Automated Vehicles for People with Disabilities	Appendix X
Breakout 25: Ethical and Social Implications	Appendix Y

Research Poster Sessions

Title	Presenters
Auction-Based Reservations of Network Trajectories for Autonomous Vehicles	Michael Levin, <i>University of Texas at Austin</i>
Hardware in the Loop Testing of Signalized Intersection Approach and Departure with Connected and Automated Vehicles	Jiaqi Ma, Fang Zhou, and Zhitong Huang, <i>Leidos</i> ; and Chris Melson, <i>Federal Highway Administration</i>
Model State and Federal Laws for Automated Driving	Bryant Walker Smith, <i>University of South Carolina</i>
Microsimulation of an Autonomous Taxi System in Munich	Florian Dandl and Klaus Bogenberger, <i>Munich University of the Federal Armed Forces</i>
Americans' Intent to Adopt Autonomous, Electric, and Shared Vehicle Technologies	Neil Quarles and Kara Kockelman, <i>University of Texas at Austin</i>
Robust Autonomous Lane-Keeping: Localizing Ground-Penetrating Radar Temporal Map Stability	Byron Stanley and Matthew Cornick, <i>MIT Lincoln Laboratory</i> ; Babak Memarzadeh, <i>Geophysical Survey Systems, Inc.</i>
A Mixed-Traffic Capacity Analysis and Lane Management Model for Connected Automated Vehicles: A Markov Chain Method	Amir Ghiasi, Omar Hussain, and Xiaopeng Li, <i>University of South Florida</i> ; Sean Qian, <i>Carnegie Mellon University</i>
Know It by Name: Human Factors of ADAS Design	Kelly Funkhouser, Elise Tanner, and Frank Drews, <i>University of Utah</i>
Connected Vehicle-Enabled Proactive Signal Control for Congestion Mitigation on Arterial Corridors	Hao Yang, Xing Wu, and Mm Haque, <i>Lamar University</i>
Development and Assessment of Speed Harmonization Algorithm Under Mixed Traffic Environment	Brian Park and Seongah Hong, <i>University of Virginia</i> ; Andreas A. Malikopoulos, <i>University of Delaware</i> ; and Joyoung Lee, <i>New Jersey Institute of Technology</i>
Deeper Understanding of Americans' Autonomous Vehicle Preferences: Long-Distance Travel, Ridesharing, Privacy, and Crash Ethics	Kara Kockelman and Krishna Murthy Gurusurthy, <i>University of Texas at Austin</i>
Transfer from Highly Automated to Manual Control: Encountering a Slow Lead Vehicle	Chris Schwarz, Timothy Brown, and John Gaspar, <i>National Advanced Driving Simulator</i> ; and Clara Keum, <i>UI Dept of Epidemiology</i>

Title	Presenters
Developing a Distributed Cooperative Eco-Approach and Departure System at Signalized Intersections Using V2X Communication	Ziran Wang, Guoyuan Wu, and Matthew Barth, <i>University of California, Riverside</i>
Using Infrastructure to Creating Necessary Redundancy in Connected Vehicle Systems and the Advantages to Enabling Cooperative Driving	Pragun Vinayak, Michael Motro, Patricia Lavieri, James Kuhr, Robert Heath, Joydeep Ghosh, and Chandra Bhat, <i>University of Texas at Austin</i>
A Systematic Approach to Evaluating Vehicular Communication and Sensor Technology in a Real-World Setting	Patricia Lavieri, Pragun Vinayak, James Kuhr, Robert Heath, Joydeep Ghosh, and Chandra Bhat, <i>University of Texas at Austin</i>
Understanding a Driver's First Exposure to ADAS and Its Impact on Future Consumer Education	Ashley McDonald, <i>University of Iowa National Advanced Driving Simulator</i> ; Daniel McGehee, Michelle Reyes, and Cheryl Roe, <i>University of Iowa</i>
New Mobility Street Design: A Case Study of Autonomous Vehicles in San Francisco	Melissa Ruhl, <i>Arup</i> ; Will Baumgardner; Gerry Tierney, <i>Perkins+Will</i> ; Sarah Ahmadzai; Justin Walker; and Allison Dawson
Queue Forecasting-Based Eco-Approach and Departure Algorithm in Urban Arterials Using Multi-Source Sensor Data	Fei Ye, Peng Hao, and Matthew Barth, <i>University of California, Riverside</i>
Cooperative Vehicle Environment Cognition Through Communication of Processed Sensor Data	Yaser Fallah, <i>University of Central Florida</i> ; Gaurav Bansal, <i>Toyota ITC, California</i> ; Shimizu Takayuki, <i>Toyota ITC</i> ; and Ahmed Sidiya Cheick and Xin Li, <i>West Virginia University</i>
Exploring SHRP 2 Navigation Data Specifications from the Perspective of Self-Driving Cars in Difficult Driving Conditions	Subasish Das, <i>Texas A&M Transportation Institute</i>
Probabilistic Field Approach for Highway Driving Risk Assessment in Mixed Traffic with Conventional and Automated Vehicles	Meng Wang, Freddy Antony Mullakkal Babu, Bart van Arem, and Riender Happee, <i>Delft University of Technology</i>

Special Interest Poster Sessions

Title	Presenters
Real-Time Implementation and Validation for Automated Path Following Lateral Control Using Hardware-in-the-Loop Simulation	Adit Joshi, <i>Ford Motor Company</i>
Where Will Automated Vehicles Take Us: A Framework for Impact Assessment	Scott Smith and Hannah Rakoff, <i>Volpe Center, U.S. Department of Transportation</i> ; Satu Innamaa, <i>VTT Technical Research Centre of Finland</i> ; Yvonne Barnard, <i>University of Leeds</i> ; Helena Gellerman, <i>SAFER</i> ; and Ryota Horiguchi, <i>University of Tokyo</i>
Enabling High-Efficiency Control Systems for Connected and Automated Class 8 Trucks	Greg Shaver, Alex Taylor, and Cody Allen, <i>Purdue University</i>
Managing Automated Vehicles Enhances Network	Jaap Vreeswijk, <i>MAP Traffic Management</i>
Mixed-Function Automation in Naturalistic Settings	Myra Blanco, Sheldon Russell, Vikki Fitchett, and Tammy Trimble, <i>Virginia Tech Transportation Institute</i> ; and Paul Rau, <i>NHTSA</i>
Connected and Automated Driving in Finland: Ongoing Pilots and Projects	Eetu Pilli-Sihvola, <i>Finnish Transport Safety Agency</i> ; and Risto Kulmala, <i>Finnish Transport Agency</i>
Advancing Automated Vehicle Pilot Projects and Deployments Through the Florida Department of Transportation's Automated Vehicle Initiative	Ben Walker and Ed Hutchinson, <i>Florida Department of Transportation</i>
Accessible Transportation Technologies Research Initiative Way Forward	Mohammed Yousuf, <i>ATTRI Program Manager, FHWA</i> ; Bob Sheehan, <i>Intelligent Transportation Systems Joint Program Office, U.S. Department of Transportation</i> ; and Rik Opstelten, <i>Hendrik, FTA</i>
U.S. Department of Transportation Research on Transit Automation and Low-Speed Automated Vehicles	Elizabeth Machek, Sean Peirce, Joshua Cregger, Margo Dawes, Eric Burkman, Anthony Thomas, and Heather Richardson, <i>Volpe National Transportation Systems Center</i> ; Kevin Dopart, <i>Intelligent Transportation Systems Joint Program Office, U.S. Department of Transportation</i> ; and Steve Mortensen, <i>Federal Transit Administration</i>
Federal Highway Administration Automated Vehicle Policy Gaps Analysis and Strategic Planning	Carl Andersen, <i>Federal Highway Administration</i> ; Anita Kim, Aaron Jette, Anthony Thomas, David Perlman, and Ben McKeever, <i>Volpe National Transportation Systems Center</i>
Connected Vehicles and Automated Vehicles Research Activities at the Transportation Research Board	Ray Derr and Stephan Parker, <i>Transportation Research Board</i>

Title	Presenters
An Integrated Safety Assessment Tool for Connected and Automated Vehicles Under Cyber-Attack	Brian Park and Lian Cui, <i>University of Virginia</i> ; and Jia Hu, <i>Federal Highway Administration</i>
Smart Belt Coalition: A Multijurisdictional Approach to Testing and Deployment of Connected Vehicles/Automated Vehicles and Emerging Technologies	Carla Bailo, <i>The Ohio State University</i> ; Courtney Ehrlichman, <i>Carnegie Mellon Traffic 21 Institute</i> ; Cynthia Jones, <i>Ohio Department of Transportation</i> ; John Maddox, <i>American Center for Mobility</i> ; Brett Roubinek, <i>Transportation Research Center</i> ; and Matt Smith, <i>Michael Baker International</i>
Wienzwa on Test Regions: Public Acceptance of Autonomous Driving and Its Impacts on Road Safety in Austria, Europe, and Beyond	Daniela Patz, <i>Smart Safety Solutions</i>
Texas Automated Vehicle Proving Grounds Partnership: Open for Innovation	Christopher Poe, <i>Texas A&M Transportation Institute</i> ; Chandra Bhat, <i>University of Texas</i> ; and Michael Brown, <i>Southwest Research Institute</i>
Cooperative Adaptive Cruise Control: Going Beyond Longitudinal Speed Control	Paolo Rinelli, Geline Canayon, Andreu Tarridda, and Laura Torres, <i>Transport Simulation Systems</i>
An Autonomous Shuttle Platform for Evaluating Control and Obstacle Avoidance Strategies	Garrison Neel and Srikanth Saripalli, <i>Texas A&M University</i>
A Demonstration of Fusing Dedicated Short-Range Communication and Radar for Optimizing Intersection Performance	Patrick Emami, Mahmoud Pourmehrab, Lily Elefteriadou, Sanjay Ranka, and Carl Crane, <i>University of Florida</i>
A Real-Time Data-Driven Decision-Support Toolkit for the Incentivization and Guidance of Shared, Electrified, and Automated Vehicles	Chenfeng Xiong and Lei Zhang, <i>University of Maryland, College Park</i> ; and Yafeng Yin and Mehrdad Shahabi, <i>University of Michigan, Ann Arbor</i>
Most Reliable Solid State Lidar	Filip Geuens,; and Kris De Meester
The Future Digital Driver: Exploring the User Experience of Generation Z in Germany to Create Intuitive Vehicle Cockpits	Evin Bahar Guenes, <i>Valeo</i> ; and Schalter und Sensoren, <i>GmbH</i>
Consumer Acceptance of Autonomous Vehicles: A Pilot Project	Manon Feys and Lieselot Vanhaverbeke, <i>Vrije Universiteit Brussel</i>
Business Case for Utilizing Highway Median Shoulders for Connected and Autonomous Vehicle Deployment	Amir Shahpar, Alireza Gerayeli, Chris McGuire, and Phillip Baker, <i>AECOM</i>

APPENDIX A

Breakout Session 1: Research to Examine Behavioral Responses to Automated Vehicles

ORGANIZERS

Johanna Zmud, *Texas A&M Transportation Institute*; Yoram Shiftan, *Technion*; Chandra Bhat, *University of Texas at Austin, Center for Transportation Research*; Ram Pendyala, *Arizona State University*; Kristin Kolodge, *J.D. Power and Associates*; Barbara Lenz, *German Aerospace Center, DLR*; Maren Outwater, *Resource Systems Group*; and Joan Walker, *University of California, Berkeley*

LIAISON

Don MacKenzie, *University of Washington*

REPORTERS

Johanna Zmud, *Texas A&M Transportation Institute*; Patricia Lavieri, *University of Texas at Austin, Center for Transportation Research*; and Felipe Dias, *University of Texas at Austin, Center for Transportation Research*

SESSION FOCUS

The goal of the session was to identify research needs and develop research approaches (both quantitative and qualitative) 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, and how they get there.

After the symposium, the organizers intend to produce a draft synthesis describing a 3- to 5-year “research roadmap” of behavioral studies that identifies priority areas of research and associated research questions. It will also outline best practice research approaches to obtain behavioral insights and address questions of interest.

PowerPoints of most of the presentations are available on the AUVSI website at <https://higherlogicdownload.s3.amazonaws.com/AUVSI/14c12c18-fde1-4c1d-8548-035ad166c766/UploadedImages/2017/PDFs/Proceedings/BOs/Bo1.pdf>.

SESSION SUMMARY

Short presentations introduced the three priority areas' key research questions, with speakers discussing research methods and considerations revolving around the questions. A presentation on the VOT was included because it is an important topic with significant implications for land use choices and activity–travel choices.

Vehicle Ownership and Use

Johanna Zmud, *Texas A&M Transportation Institute*

Barbara Lenz, *German Aerospace Center, DLR*

Zmud and Lenz discussed the following questions.

- Will AVs be deployed as personalized AVs or ridesharing AVs? The speakers suggested that looking at vehicle ownership versus usage today, the answer seems to be biased toward personally owned vehicles. Over 90% of U.S. households own an automobile. Only 9% of households do not own a car. A 2016 Pew Research Center study¹ on the sharing economy indicated that only 15% of American adults have used ridesharing apps. The majority of these users are also vehicle owners and drive a car regularly. The situations in which they use ride-hailing suggest occasional, supplemental use to their regular driving, such as while traveling or on occasions when they are consuming alcoholic beverages. The speakers suggested that there are factors that point toward shared-vehicle deployment. Fully autonomous vehicles need to be near perfect in operation. As a result, early applications may be route-constrained, which fits a business model of autonomous fleets. The private AV market may take longer to develop due to ADAS deployment speed, market demand, fleet turnover, state and local policy, and other factors. The speakers noted that method considerations are tracking industry trends and tracking studies of attitudes and opinions. They further noted that acceptance influences adoption.

- Who are the early adopters of AV and sharing services at different stages of automation? The speakers suggested that the pilot AV sharing studies in Pennsylvania, Arizona, California, and Texas provide the opportunity to examine the experience, attitudes, and opinions of pilot participants and if they differ from those who are nonparticipants. The speakers suggested that the experience of being a pilot participant may affect preferences for owning or sharing AVs.

- What are factors affecting sharing? The speakers discussed that to understand future behavior in the context of AVs, research is needed on how people are using shared mobility now. They noted that many people hypothesize that current rideshare users will be early adopters of AVs. They asked under what conditions does sharing complement ownership and substitute for it? How is that differentiated by geography and demographics? They noted that methods that could be used to examine these topics include interviewing drivers, asking specific follow-up questions to large-scale travel surveys, using real-time tracking, and monitoring data.

Note

1. http://assets.pewresearch.org/wp-content/uploads/sites/14/2016/05/PI_2016.05.19_Sharing-Economy_FINAL.pdf.

Land Use Choices

Eric Miller, *University of Toronto*

Yoram Shiftan, *Technion*

Miller and Shiftan discussed the following questions.

- Will the changes brought by AVs be structural or they will just magnify or reduce effects that already have been observed? The speakers discussed that for AVs to have significant impact on residential location they actually have to deliver in terms of significantly faster travel times and provide a productive vehicle–trip environment (e.g., happy to work within the vehicle rather than at home or at work). AVs also have to be viewed as trustworthy for chauffeuring children and older adults. The speakers noted that even if adopted, people may simply change travel behavior “in place” rather than move. They suggested that while many of the claims for AVs are unproven at the moment (and arguably even quite dubious), there is a need to study their potential impacts. The speakers further suggested that a starting point for delving deeper into residential location preferences would be to address the following questions:
 - What do people really want and why?
 - What are the actual constraints on their current residential locations?
 - How do they view the location and travel tradeoff?
 - How does accessibility actually enter into their decisions and behaviors?
- The speakers discussed that, as with just about all aspects of AVs, the big question is obtaining a more fundamental, deeper understanding of current behavior, preferences, and decision processes. This information would help predict how people would react in the face of new technologies and services. They noted that in theory, one should be able to construct stated-preference experiments to explore these issues. However, they acknowledged that this would be very challenging due to the high dimensionality of the problem, massive uncertainties, alternatives that include both residential location alternatives and travel alternatives, and uncertainty on how to pose the problem.
 - The speakers suggested that residential location shifts could probably take a long time to play out and that AV impacts are probably going to be much longer-term than many advocates claim. As a result, there is time to conduct some fundamental research.

Activity and Travel Choices

Chandra Bhat, *University of Texas at Austin*

Mark Bradley, *Resource Systems Group*

Bhat and Bradley discussed the following questions and topics.

- How do daily activity and travel patterns change (activities, schedules, departure time, modes, destinations, and with whom) with fully AVs? The speakers noted that in terms of travel, today’s mobility-constrained groups (including seniors and physically challenged individuals) will have more mobility freedom and may generate more out-of-home (OH) participation and travel. More generally, individuals may participate more in OH activities, and generate more trips. There may be less need for trip chaining and more time available for leisure OH participation. The potential for more empty trips was noted, which will depend on automobile ownership and the use paradigm.

- For location choice, will people be willing to live farther away from their work place? Will people choose locations for nonwork activity participation that are farther away than current participation locations? The speakers noted that reduced parking hassles may result in more attraction to dense, attractive activity locations. People may be less likely to pursue activities (as a package) within a compact geographic footprint (i.e., potentially less incentive for activity chaining). On the other hand, there may be more attraction to activities within a compact geographic footprint if AV ridesourcing is used.

- The speakers noted that for mode choice, AVs combine the advantages of public transportation with that of traditional private vehicles (i.e., catching up on news, texting friends, reading novels, flexibility, comfort, and convenience). They questioned how this would impact public transportation. They also noted that AVs may result in lesser walking and bicycling shares (and less walking to–from parking and transit). They further noted that time (congestion and reliability) will be less of a consideration and that cost may be the main policy tool to influence behavior.

- The speakers noted that time use is central to activity-based modeling, explicit modeling of activity durations (daily activity time allocation and individual episode duration). Time is treated as “continuous” and not as “discrete choice” blocks. Activity engagement is the focus of attention and travel patterns are inferred as an outcome of activity participation and time use decisions. The continuous treatment of time dimension allows the explicit consideration of time constraints on human activities. The feedback process includes reconciling activity durations with network travel durations.

- The speakers discussed modeling implications, noting that there is a need to consider latent (and stochastic) psychological constructs to obtain “true” estimates of the effects of current residential and mobility choices on future AV-related choices. They noted that the cursory attention paid to psychological underpinnings in current modeling approaches will not suffice moving into a new transportation era of innovative mobility–technology services. They suggested the need for a better understanding of the individual observed attributes that characterize factors such as being green and tech-savvy.

Value of Time

Pat Mokhtarian, *Georgia Tech*

Ram Pendyala, *Arizona State University*

Mokhtarian and Pendyala discussed the VOT, noting that a lot is known about the influence of travel time (TT) on travel choices, including the following elements:

- Trip generation (choice to telecommute = f (commute distance, etc.);
- Destination choice (TT traded off against destination attractiveness);
- Mode choice (TT traded off against travel cost, other variables);
- Route choice (shortest path a common choice); and
- Residential location (commute cost traded off against housing cost).

They suggested that knowing how changes in the “weight” of TT in those choices is needed. They noted that the following topics also need to be examined:

- Choice set definition; and

- Shared ride with strangers may be perceived very differently than a private ride (in own or hailed vehicle).

The speakers highlighted the following questions of interest for further discussion.

- Not all minutes are created equal: how can we quantify the value of TT?
- Do we have different standards for TT than for other time?
- What is our reference point?
 - Zero expected value (therefore any positive benefit is a “bonus”)?
 - Full value we would receive for those same minutes if not traveling?
 - Maximum possible value?
- The speakers questioned how do the activities people engage in while traveling differ from their preferred (or, next-best) alternative?
 - To what extent are the activities we conduct while traveling an unconstrained choice (something we would have done anyway) versus “the best we can do, given that we are traveling”?
 - To what extent are they entirely new activities that would not have occurred otherwise (thus replacing nothing, maybe not “creating time” at all)?
 - More generally, what are the interactions of TT with non-TT (and the impacts on others)?

The speakers discussed the following analysis tools:

- Data collection platforms (focus groups, stated-response surveys, revealed-preference surveys, smartphone apps, and social media);
- Data collection times (cross sectional, continuous, and longitudinal);
- Nature of the data (qualitative—ask people, study the past, qualitative/quantitative—chauffeur study);
 - Models (theoretical models of destination, mode, residential location choices, time allocation models that account for TT use, account for heterogeneity); and
 - Disciplines (economics, psychology, sociology, anthropology, geography, urban planning, engineering, computer science, history, law, and public health).

SUGGESTED ACTION ITEMS

Participants discussed the need to practice using combination of different research approaches to answer these complex questions. Because this is an evolving area, the need to collect time use—longitudinal data was also noted by participants.

- Participants discussed the need for research to follow changes in perceptions and attitudes including comparing changes between places with different development and market penetration rates.
- Participants identified the need to document and analyze longitudinal data from existing and future evolving shared mobility services.

- Participants supported coordinating surveys with field experiments to build upon existing survey instrument tools and leveraging technology to collect data.
- Participants identified needed research to improve stated-preference survey methods including the use of VR, gaming, and movies.
 - Participants noted that conducting more naturalistic studies would be beneficial.
 - Participants discussed the need to collect and analyze qualitative data: interviewing people and conducting focus groups to better understand peoples' motives and goals and to collect more psychometric indicators.
 - Participants noted the importance of long-term learning; there is a need to develop standard questions to include in various surveys and field experiments so results can be tracked across geographies and across time.

APPENDIX B

Breakout Session 2.1: Judging a Car by Its Cover

Human Factors Implications for Automated Vehicle External Communication

ORGANIZERS

Andy Schaudt, *VTTI*; John Shutko, *Ford Motor Company*; and Sheldon Russell, *VTTI*

REPORTERS

Sheldon Russell, *VTTI*; and Ruth Madigan, *University of Leeds*

SESSION FOCUS

Currently road users communicate with one another in numerous ways. They communicate through eye contact, hand gestures, turn signals, horns, and even the control of their movement to show intent (e.g., easing a vehicle forward). Uncertainty exists as to whether HAVs will be able to perceive and communicate intent in the same ways that a human can. Therefore, HAVs should be designed to signal their intent in ways other roadway users can reliably understand. This session brought together professionals to discuss how HAVs should communicate with all roadway users; what information is needed to communicate; and to what degree standardization of HAV external communication could be valuable. The session will provide presentations from experts currently researching this area. There was also an exercise to explore further use cases of HAVs and their interactions with other vehicles; and VRUs and how the application of human factors design principles could lead to potential solutions to these challenges.

PowerPoints of most of the presentations are available on the AUVSI website at <http://www.automatedvehiclessymposium.org/avs2017/program/proceedings>.

SESSION SUMMARY

This session included three presentations followed by three interactive exercises.

- John Shutko, *Ford Motor Company, presenter*. Shutko discussed current activities with HAV communication from ISO. An ISO meeting was held in Gothenburg, Sweden, in the spring of 2017, which included various international contributors. Shutko noted that current driver and vehicle interactions with pedestrians include vehicle motion, hand gestures, and eye contact. He also noted that context matters with all interactions. HAV signals to facilitate communication to road users should be perceptible, communicable, and most importantly learnable. A critical need is for HAVs to communicate their intent. Shutko said that the ISO

group is planning to produce a technical report clarifying standards for HAV communication. Work is underway with agreement on the purpose, scope, and outline. The final report is expected to be completed in 2018.

- Satoshi Kitazaki, *National Institute of Advanced Industrial Science and Technology, presenter*. Kitazaki discussed a research project, “Effects of Nonverbal Communication Cues on Decisions and Confidence of Drivers at an Uncontrolled Intersection.” The research examined how current road users use nonverbal cues and how these change drivers’ actions and confidence. The research study participants reviewed a simulation of different conflict scenarios and were interviewed to provide feedback and confidence ratings about each scenario, along with hand gestures demonstrated by an experimenter. The results showed that hand gestures were especially effective at influencing driver behavior. Possible implications of these results for HAV communication were discussed by breakout session participants.

- Ruth Madigan, *University of Leeds, presenter*. Madigan discussed the needs of pedestrians when interacting with AVs. She suggests that when there is no driver in the vehicle, there needs to be a replacement for gestures to communicate with other vehicles. She noted that the communication requirements may change based on the HAV design. She described the proposed communication methods as well as recent research projects evaluating different communication methods. Information from the CityMobil2 project also was presented and discussed. This project used interviews, focus groups, and on-site interviews to explore participant acceptance and interaction with HAVs in multiple sites. She noted that participants reported that they were most interested in knowing whether or not the HAV had detected their presence. Modality of communication was discussed, but there was no clear consensus about the best modality across the different research sites. Comments from focus groups included the ability to see messages from HAVs, the responsibility of the driver, and the use of dedicated versus shared spaces for HAVs.

BREAKOUT SESSION EXERCISES

Schaudt presented three exercise scenarios discussed by participants. A video of each scenario was presented followed by participants discussing questions in smaller groups. A full group discussion wrapped up each exercise. The scenarios are described in the following; including the discussion questions. The major points discussed are summarized as part of the action items and research needs.

Exercise A: Right-of-Way Conflict

Scenario Description: An HAV approaches a signalized intersection with a green traffic light, indicating that the HAV has the right-of-way, but a pedestrian is walking across the HAVs intended path on a crosswalk.

- Identify right-of-way roles/conflicts.
- Identify pedestrian characteristics that could affect the interpretation of external communication:
 - Knowledge transfer from previous experiences (negative? positive?); and
 - Other assumptions/expectations.

- Identify the stages of the HAV state (steady forward motion, deceleration, stop, acceleration).
- Identify the HAV intent and explore potential conflicts with the HAV state.
- Should the HAV communicate state, intent, or both?
- How should the HAV communicate (visual, auditory, both)?
- Human factors design considerations:
 - Visibility of system status;
 - Match between system and real world;
 - Consistency and standards;
 - Minimalist design;
 - Help users recognize, diagnose, and recover from errors; and
 - Proposed communication method(s)/solution(s).

Exercise B: Park, Pick Up, and Proceed

Scenario Description: An HAV is proceeding straight in the right travel lane and pulls over to the right side of the road to pick up a passenger. The HAV then proceeds back into the traffic stream.

- Identify relevant road user types, locations, and characteristics that could affect the interpretation of external communication.
- Road user types:
 - Other vehicle drivers;
 - Pedestrians (on sidewalk, at crosswalk); and
 - Bicyclists (on sidewalk, traveling with traffic, traveling in bike lane).
- Road user locations:
 - Ahead of HAV (in lane, on sidewalk);
 - Behind HAV (in lane);
 - Left of HAV (in lane); and
 - Right of HAV (in lane, in parking area, on sidewalk).
- Knowledge transfer from previous experiences (negative? positive?).
- Other assumptions/expectations.
- Identify the stages of the HAV state (steady forward motion, deceleration, lane change, stop, acceleration, lane change).
- Identify the HAV intent and explore any conflicts with the HAV state.
- Should the HAV communicate state, intent, or both?
- How should the HAV communicate (visual, auditory, both?).
- Human factors design considerations:
 - Visibility of system status;
 - Match between system and real world;
 - Consistency and standards;
 - Minimalist design; and
 - Help users recognize, diagnose, and recover from errors.
- Proposed communication method(s)/solution(s).

Exercise C: An HAV Encounters a Vehicle Entering the Roadway

Scenario Description: An HAV is proceeding straight in right lane of highway, with traffic in the left adjacent lane. As another vehicle enters the roadway from an onramp on the right. The HAV will either have to decelerate or accelerate to allow vehicle to enter the roadway.

- Identify relevant road user types, locations, and characteristics that could affect interpretation of external communication.
 - Road user types:
 - Other vehicle drivers;
 - Pedestrians (on sidewalk, at crosswalk); and
 - Bicyclists (on sidewalk, traveling with traffic, traveling in bike lane).
 - Road user locations:
 - Ahead of HAV (in lane, on sidewalk);
 - Behind HAV (in lane);
 - Left of HAV (in lane); and
 - Right of HAV (in lane, in parking area, on sidewalk).
 - Knowledge transfer from previous experiences (negative? positive?).
 - Other assumptions/expectations.
- Identify the stages of HAV state (steady forward motion, deceleration, lane change, stop, acceleration, lane change).
- Identify the HAV intent and explore any conflicts with the HAVs state.
- Should the HAV communicate state, intent, or both?
- How should the HAV communicate (visual, auditory, both)?
- Human factors design considerations:
 - Visibility of system status;
 - Match between system and real world;
 - Consistency and standards;
 - Minimalist design; and
 - Help users recognize, diagnose, and recover from errors.
- Proposed communication method(s)/solution(s).

SUGGESTED ACTION ITEMS

Participants identified the following research questions from the discussion on the exercise scenarios.

- Two-way communications. Can vehicles sense or detect the intent of other road users? Will one-way communication be enough (e.g., vehicles display their intent but do not recognize other road user behavior)?
 - How will HAVs respond to emergency vehicles?
 - Intent changes over time, and potentially at a moment's notice. When and how should these changes be communicated?
 - How much and what information that is displayed to external users (pedestrians, other traffic, etc.) is also displayed to the HAV passengers/operators?

- This would include specialized communications for HAVs intended for use as taxis.
- What is the potential that alerting or communication strategies may extend an event rather than resolve it?
 - There are likely situations that don't require development of additional communication modalities/methods.
 - Understanding when to use vehicle movement as a communication device (e.g., highway merging).
- What is the effect of roadways changing between shared lanes or dedicated lanes, and how is this communicated to all road users?
 - Should HAV communication be sociable? This might include emotion expression (regional variations/dialect integrated into communications).
 - What is the social responsibility of either pedestrians or vehicles communicating (or intentionally not communicating)? Will pedestrians intentionally step in front of HAVs because pedestrians know it will stop?
 - Would this be more probable if the HAV was empty (e.g., more socially acceptable)?
 - Will notifications of yielding to pedestrians promote violation of right-of-way laws?

APPENDIX C

Breakout Session 2.2: Automated Vehicle Challenges *How Can Human Factors Research Help Inform Designers, Road Users, and Policy-Makers?*

ORGANIZERS

Anuj K. Pradhan, *University of Michigan Transportation Research Institute*; Chris Schwarz, *University of Iowa National Advanced Driving Simulator*; Fred Feng, *University of Michigan Transportation Research Institute*; John Sullivan, *University of Michigan Transportation Research Institute*; and Shan Bao, *University of Michigan Transportation Research Institute*

REPORTER

Fred Feng, *University of Michigan Transportation Research Institute*

MODERATOR

Ed Neidelmeyer, *Tesla*

SESSION FOCUS

This session focused on discussing the probable consequences of vehicle automation on humans adapting to these new technologies. Session panelists came from industry, government, and academia outside the traditional human factors research community in an effort to understand the indirect effects that extend beyond immediate issue of vehicle control and operation, as automation may alter how people have traditionally thought about mobility. These changes are expected to have consequences on the behavior of all road users.

SESSION SUMMARY

Following introductions by Chris Schwarz and Anuj Pradhan the four panelists in the session made brief opening comments. The panelists then responded to questions and engaged in an open discussion with session participants.

- Alex Epstein, *Digital Strategy and Content, National Safety Council*. Epstein noted that educating the public about the AV functions was important, as various technologies are not always intuitive. He suggested that more training should be provided on the functions and use of

ADAS, as it is difficult for customers to find information from manufacturer's websites or from dealers. He reported that the MyCarDoesWhat campaign provides information to the public about ADAS. The MyCarDoesWhat website is averaging 1 million hits a year.

- Emily Frascaroli, *Ford Motor Company*. Frascaroli discussed potential regulatory issues, noting that there are requirements at the federal and state levels. She suggested that the liability issue was contextual. The police will focus on who is responsible, while insurance companies will be concerned with who is paying. She noted that people are creative and will find ways to overcome possible limitations of the system. She identified one important question as who is responsible for customer's misuse of the system?

- Nidhi Kalra, *RAND*. Kalra engaged the audience in considering how safe an AV needs to be for it to be allowed on the road. Same as the average human driver? Twice as good? Near perfect? Worse? The near perfect measure received the largest support. She suggested that humans are not good at judging risks, because humans are not rational and risk is not consistent. She further suggested that there was a need for an evidence-based way of assessing risks.

- Bernard Soriano, *Director, California DMV*. Soriano reported that 36 companies account for approximately 250 vehicles that have received AV testing permits in California. Further, some 800 drivers have permits to drive the test vehicles. He noted that to date 34 crashes and disengagements from the automated phase back to the driver have been reported by the companies. He noted that the rule-making process on driverless vehicles is underway in California. The DMV has been conducting public hearings and engaging stakeholders in the development process. He noted that there are potential safety benefits from driverless vehicles and there is a desire to foster the innovation and development in the state, but that safety must still be the top considerations.

The panelists discussed the following topics.

- Panelists discussed trusting AVs both as a driver and passenger and as a VRU. It was suggested that by definition trust means shared vulnerability and shared risk, which works with another human, but it may not work for machines. It was noted that trust often comes from direct experience. There is no real widespread experience with AVs. Building trust among consumers with lower levels of automations was suggested as an initial step. An analogy presented was driving with and without antilock braking systems. It was suggested by some panelists that education has to be continuous with technologies. Caution was also raised that users may over-trust automation and technology systems, which may undermine the trust of drivers of other vehicles and VRUs.

- Panelists discussed different methods to educate customers and provide information on the use of automated features. It was noted that customers often do not want to spend time learning new features. Using social media to provide information was discussed by participants.

- Panelists and participants discussed the various groups responsible for education, how information should be provided, and methods to keep the information updated. It was also noted that people may make trade-offs between safety and other factors. Understanding more about how people consider risks could be added to the information and training provided.

- Panelists and participants discussed putting more emphasis on driver training for all age groups now. The Ford program about driving skills for life was discussed, along with changing demographics. New ways to provide education and training, such as the Apple Siri or Google ("Ok Ford, why is this light on?") were suggested by some participants. The need to train

their automotive technicians was also noted as important. Examining requirements and legislation for driver training was discussed.

- Panelists and participants discussed the need to provide realistic expectations on the capabilities of different systems and technologies and to provide a balanced perspective. The differences in the information provided by systems and products was noted. It was suggested that humans can learn well, but that cars may be boring if all the buttons are the same. Participants also discussed the importance of considering human factors issues and user experiences.

- Panelists and participants discussed the roles of government agencies, OEMs, nongovernmental organizations, and other groups in testing and rating systems.

- Panelists and participants discussed possible similarities with other industries, including aviation and pharmaceutical companies. The potential to learn from their experiences was suggested as beneficial.

- Panelists and participants discussed using the term “augmented vehicles” for lower levels of AV automation. This term might better fill a gap between AVs and human drivers, and sounds more cooperative. It was also suggested that drawing conclusions on the user cases for different SAE automation levels would be beneficial. Participants also discussed that although human error is often the cause of most crashes, vehicle and environmental issues may be contributing factors. In addition, automakers use different methods to provide warnings. Not everyone knows how to respond to a vibrating seat (blind spot). As a comparison, it was noted that the aviation industry warnings are consistent.

- Panelists and participants were asked to identify their biggest fear in year 2023. Responses included trust in technology, overselling the technology so that there is a public backlash, and still not being able to agree on how safe AVs need to be.

- Panelists and participants discussed approaches for drivers who enjoy driving and want to continue driving in an AV future. It was suggested that even people who like driving may still welcome the AV functions, and that driving may become a recreational activity at special facilities. It was also noted that people may lose driving skills if they drive less.

The following key issues were highlighted in the summary to the full symposium.

- Driver education will become more important in the future and there will be more of a gap in the needs of different segments of the population.

- Customer acceptance is still an open question. How safe AVs need to be for public acceptance is a key question.

- People are creative and will find ways to misuse any automated driving system.

- People are not necessarily good judges of relative risks.

- It seems probable that 94% of driver errors may be hiding some vehicle and environmental issues.

SUGGESTED ACTION ITEMS

- Participants suggested that research developing and adopting new education methods would be beneficial. Approaches such as “Ok Ford, how do I ...?” could be included in the research.

- Participants discussed the need to close the gap between reality (the real capabilities of the system) and marketing. Research on this topic was suggested as beneficial.
- Participants noted that OEMs can learn from aviation and other industries and that an ongoing focus should be learning from other industry sectors.
- Participants suggested that research was needed on how to help drivers be aware of the system limitations.
- Other research needs suggested by participants were exploring if manual override should always be available and assessing the risk of skill degradation and how it should be mitigated.
- Participants noted that these topics will be developed into new research needs statements.

APPENDIX D

Breakout Session 3: Enabling Technologies for Automated Vehicles

ORGANIZERS

Carl Andersen, *U.S. DOT*; Stacy Randecker Bartlett, *Ellis & Associates*; Jennifer Carter, *HERE*; Rob Dingess, *Mercer Strategic Alliance*; Dominique Freckmann, *TE Connectivity*; Juhani Jaaskelainen, *Independent*; Jim Misener, *Qualcomm*; Sudararajan Sudharson, *Booz Allen Hamilton*; Valentin Scinteie, *Kontron*; and Virginia Stouffer, *LMI*

REPORTER

Robert Dingess, *Mercer Strategic Alliance*

SESSION FOCUS

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

SESSION SUMMARY

The session began with presentations on positioning and localization. HERE's Phillip Bernard moderated this portion of the session and the speakers included Russ Shields and Xinzhou Wu from Qualcomm. Shields' presentation centered on the difficulties in developing a reliable process for Levels 4 and 5 AV localization that supplements information provided by HD maps. He is working on a process designed to maximize the value and quantity of landmarks that could be used to enhance accuracy. He asserted that technologies such as radar and lidar are insufficient. He is focusing his research on analyzing camera imaging. One permanently recognizable feature is needed per every few meters to ensure accuracy. He noted that the costs associated with gathering this data are significant, but well within the ROI assessment for OEMs.

Wu also addressed the issue of positioning and mapping. He asserted that HD maps simply provide basic navigation and that sensors should be used to provide the needed subdecimeter relative accuracy for guidance. He noted that there are a number of key issues surrounding the use of HD maps: 1) level of accuracy; 2) finding key attributes; and 3) ensuring the freshness of the dataset. Qualcomm is developing a DDP Block diagram with a camera and a smartphone. GPS and vision systems are fused to produce 1-m accuracy. Combining this system with deep learning process key landmarks that are identifiable and greater levels of accuracy is achievable. He said that the final result is a subdecimeter level of accuracy. The vehicle data uploads to the cloud and is further processed for sharing with the network. In the process, the

camera and software detect the route corners. He noted that professional GPS services are used to enhance the accuracy of the system.

The second set of presentations addressed cybersecurity. Jonathan Petit from On Board Security served as the moderator for these presentations. Harsh Patil from LG Electronics described how today's vehicles contain up to 100 electronic control units. The addition of V2V and V2I sensors provides a new layer of complexity to the issue of security. Theft of intellectual property and privacy are issues and specific target areas include head units, engine control units, sensors, and actuators. He said that sensors are the most challenging of the targets from a security standpoint. He said that edge case security intelligence is increasing. The industry is constantly changing interactive protocols as necessary, but this provides opportunities for attack. Additional challenges are associated with cyber criminals who seek to use the vehicle as a method of hacking into Smart Homes through direct or wireless interfaces. He also noted that sensor spoofing attacks are an increasing challenge. Work is ongoing to develop spoof resistant processes. Lightweight crypto ciphers allow for nimble, yet secure processes. Post quantum crypto security is necessary.

Walter Sullivan from Elektrobit described cyber security from a more traditional OEM approach. He discussed the types of over-the-air (OTA) updating processes that Tesla has developed. He noted that OEMs have traditionally used low-level operating systems with little or no need for software updates. Tesla has built a next-generation OTA system, which is more advanced. He is working on OTA processes that will reach production in 2020 by using simple approaches with limited risk for initial OTA activities.

Six speakers addressed digital infrastructure. Maxime Flament from ERTICO described industry standards in map and sensor data protocols from the cloud, ADASIS and SENSORIS. These efforts are managed by ERTICO and fall under the Open Autodrive Forum, along with NDS.

Satoru Nakatcho from the University of Tokyo described the Japanese SIP-adus (http://www.nedo.go.jp/english/sip_ai2017.html) work on mapping, including the Dynamic Map Platform Inc. The effort includes the map, HMI, security, pedestrian accident reduction, and other elements. He noted the Japan Dynamic Map FOT, which includes 300 km of highways and ring roads in the Tokyo area. One output is to promote standardization activities to include input to ISO/TC204.

Scott Nelson discussed HERE's open location platform. He noted that the platform has been provided to the Colorado and Iowa DOTs to help develop standards for infrastructure data. Nelson described a cooperative V2X road hazard example where the road hazard information was crowdsourced.

Paul Carlson, Texas A&M Transportation Institute, described the development of a 10-Hz data collection set. The analytics are created in the cloud and a dashboard is developed for use by road owners. He noted one example of monitoring changes in the configuration of linear barriers. A second example he cited was verifying bridge clearances.

Doug Dolinar, Limtech, described their method of collected precision striping data via real-time kinematic GPS. The data is used to automatically paint lines on the recorded roads.

Participants discussed challenges with different enabling technologies and applications. Topics discussed included connections between static and dynamic maps, map updates, standardizing map definitions for various roads, the relationship between dynamic map and navigation data, and the balance between map and other key elements such as sensing devices to include in the AI algorithm.

Alan Steinhardt, AEye, provided a philosophical outlook on the strengths and use of AI. Onboard computational technologies were also discussed, including current work by Intel and NVIDIA on automation and deep learning. This discussion provided participants with an understanding of the capabilities of deep learning processors and systems. Wesley Shao, Baidu, described the development of an open-source self-driving vehicle code. He noted that it has been released through Apollo, a new industry group they have created.

The breakout session concluded with a discussion and debate on two competing radio-access technologies: 802.11p-based (DSRC in the US, ITS-G5 in Europe) and cellular V2X. John Kenney, Toyota ITC, provided background and a basis to continue with a well-tested ad hoc short-range communication technology, DSRC. Tim Lienmueller, DENSO, described the C-V2X perspective.

SUGGESTED ACTION ITEMS

- Participants identified the need to better understand how system complexity and infrastructure system preservation treatments might add new layers of complexity to various system approaches.
- Participants suggested that research was needed examining the cyber issues associated with sensor security and with software updates. Participants noted that these elements are very different in their risk portfolios and processes.
- Participants discussed options for breakout sessions at the 2018 AVS. One option identified was developing two sessions: one on onboard technologies and one on technologies that depend on infrastructure. Maintaining one session with a systems perspective was also discussed.

APPENDIX E

Breakout Session 4: An Automated Vehicle Crashes *What Happens Next?*

ORGANIZERS

Karlyn Stanley, *RAND Corporation*; Ellen Partridge, *Environmental Law & Policy Center*; Carl Andersen, *FHWA, U.S. DOT*; James Anderson, *RAND Corporation*; Todd Benoff, *Alston & Bird*; Ryan Gammelgard, *State Farm Insurance Company*; Don Slavik, *Slavik Law Firm*; Dorothy Glancy, *Santa Clara University School of Law*; Ryan Harrington, *Exponent*; Austin Hensel; Nira Pandya, *UC Berkeley Law School*

PANELISTS

James Epperson, *California Highway Patrol*; James Anderson, *FHWA, U.S. DOT*; Ryan Gammelgard, *State Farm Insurance Company*; Todd Benoff, *Alston & Bird*; Don Slavik, *Slavik Law Firm*; and Ryan Harrington, *Exponent*

MODERATORS

Karlyn Stanley, *RAND Corporation*; and Ellen Partridge, *Environmental Law & Policy Center*

REPORTERS

Nira Pandya, *UC Berkeley Law School*; Karlyn Stanley, *RAND Corporation*; and Ellen Partridge, *Environmental Law & Policy Center*

SESSION FOCUS

Crashes are inevitable, even with the safest of systems. The goal of the session was to identify how the various parties who enter the picture after a crash will do things differently when the crash involves an AV. Interested parties include law enforcement, insurance experts, investigators, and products liability lawyers on the plaintiff and defense sides. What types of data will they look for from the AV and what will be the impact of the new technology on existing liability laws?

SESSION SUMMARY

The following scenarios were used to highlight questions of interest:

- An AV goes over a cliff after a rockslide in icy conditions. A Level 5 vehicle was programmed to take an alternate route when there was a crash on its regular route. On the alternate route, a rockslide occurred and the car slid off the icy road and over the cliff.
- A human-driven car rear-ends an AV. The most common type of two-car collision is a rear-end collision when the lead vehicle is stopped at an intersection. Here, one vehicle is a Level 4 AV driving within its ODD. The other is not an AV and is operated by a human driver. The AV comes to a stop when its cameras sense that the traffic light is yellow, and based on the AV's speed and distance from the intersection it will not be able to enter the intersection before the light changes to red. The vehicle piloted by the human driver fails to stop, and rear-ends the AV.
- An AV under the control of hacker a runs into a human-driven car. The cars have switched positions. Now the human driven car is stopped at the intersection, and the AV causes the rear-end collision when a hacker takes control.
- A collision occurs because the smart infrastructure fails. The AV is in the lead. Both vehicles have V2X and the traffic light is on the network. However, the light sends faulty data to that AV, telling it the light is red, when the green signal lamp is lit. The AV stops, but the human driver who is looking at the green light does not expect this and hits the AV.

For each scenario, experts from law enforcement, insurance, investigation, and plaintiff and defense bar discussed issues about how they would respond to the scenario.

Issues Noted by Law Enforcement Personnel

- Witnesses. There are now two kinds of “witnesses” to interview, the human driver and the data collection devices on both vehicles. Although much more data is potentially available, when law enforcement first arrives on the scene, officers will not generally be looking at electronic data recorders (EDR), or impounding or preserving them. That is not the primary job of law enforcement and a warrant would typically be required for law enforcement to take custody of the EDR.

Issues Noted by Insurance Experts

- Data. Insurance representatives are not the first on the scene and have little control over securing EDRs. What is the obligation of public agencies to provide accurate weather and road condition data?
- New insurance products. Developing and pricing insurance policies for cybersecurity concerns is a new arena for insurance. Products may offer different coverage for intrusions such as ransomware, dedicated denial of service, spoofing sensors, and taking control of the vehicles.

Issues Noted by Plaintiff and Defense Lawyers

- **Data.** The information that lawyers look for as they work to assess liability may go beyond the information available at the scene. It could include, for example, data generated days before the accident, biometric data (Were the driver's eyes falling asleep? Did the driver have sleep apnea?), cell phone and personal computer data linked to the car's systems (Was the driver distracted?), and data from nearby vehicles. What are the privacy implications for data from the car and the other data that is arguably related to an assessment of liability?

Do not assume that everything the EDR says is true. Physically impossible behavior sometimes is reported. "In litigation, we have found situations that EDR data is not always right, like the 175-mph Toyota Takoma. It did not happen but it said it did." EDRs are NOT perfect witnesses. "But, EDR data is better than eyewitness testimony. Cannot assume all data is bad data. Lot of cases are pedal confusion cases."

- **Liability.** Car manufacturers could be the first victims of hacking to be subject to strict liability. Prior cyberattacks on restaurants and stores triggered the economic loss doctrine; that defense will not be available when a hack causes an AV to crash. For malfunctioning infrastructure, the issues are complicated because the human driver's responsibilities are complex. What should the AV be programmed to do when it is stopped at a red light and a human driven car approaches from the rear with no time to stop? Should the human driver "need" a warning that a car is stopped at a light 200 m away?

Issues Noted by Investigation Expert

- **Data.** When smart infrastructure fails, nearby vehicles not involved in the crash may be "eyewitnesses" to messages broadcast on the network. Is it really a hack or is it a computer malfunction? Data that is stored on an EDR needs to be standardized. When you think about radar, lidar, and camera data, how do you store it reliably? Storage on a vehicle is not like storing data on a hard drive. There is a question about how far back the data is kept. You cannot store real-time data, there needs to be triggers for it.

- **ML.** How fast can we expect the AV to react to conditions such as a rockslide? Should the machine be alert to such possibilities if there are snow or rain weather predictions? How up-to-date should the weather predictions be and how quickly should the AV learn to handle changing local conditions? At what point should an AV refuse to take the alternate route?

- **Human condition.** How should the condition of the human driver be assessed as relevant or not with a Level 5 vehicle? What if the human was tired and had been drinking when he/she reprogrammed the car?

KEY FINDINGS

- Liability standards will continue to be debated by plaintiff and defense lawyers.
 - What standard should an AV be held to? Should it be held to higher levels because it is a computer and expected to perform better than a human driver? Plaintiffs may suggest that the technology should be held to a higher standard—it should be judged against the best human driver you can have under the circumstances.

– **Strict Liability Regime:** Should AVs be subject to strict liability if there is an accident? What about when there is a hack? Defense lawyers suggested that AVs should be held to a higher standard using the negligence regime, not strict liability. The AV is now the driver. Drivers have never been held to a strict liability standard. In terms of hacking, automakers should not be held to strict liability, either. Governments have been hacked but they are not subject to strict liability, so why should automakers be?

- Law enforcement investigation will not change much—at least initially. Law enforcement needs to be aware if it is an AV crash and to secure the scene. As with any crash, lifesaving and treatment of the injured is the first priority. Law enforcement may need to make sure the vehicle does not drive away. New issues arise with understanding immediately what controls are present and how the vehicle can be disabled to make sure that there is no loss of data at the time.

- The insurance industry does not view AVs as an existential crisis, but views the technology as an opportunity to continue creating products that help people and companies manage risk. Insurance companies have a vested interest in the development of AV technology. The insurance industry has begun to coalesce around the idea that this is a fundamental shift to their business model. By law, insurance companies are required to price products according to the associated risk. Right now, there is no data that can assist with pricing, but there will potentially be many different products and regimes as data are developed. Insurance companies need access to data in order to price the risk.

SUGGESTED ACTION ITEMS

Participants discussed that while crashes may occur less frequently with AVs, they will still occur and liability questions will have to be addressed. The greater amount of data that will be available will assist in the determination of liability. Responsibility of public agencies for providing data to the vehicles, such as weather information, is an open question. Responsibility may be increased or sovereign immunity may prevail. Participants identified the following questions for further research.

- Research the appropriate amount and types of data that should be captured by EDRs, along with the methods of reliable storage.
- More research on cybersecurity measures is needed including firewalls and domain separation.
- Participants identified that research clarifying the sources and integration of critical data concerning infrastructure, weather, and road conditions was needed.
- Research clarifying the responsibilities of the vehicle owner–operator (and the OEM) for providing timely software updates, and assessing if sensors and other safety systems are properly maintained was also noted as needed by participants.
- Research reviewing new insurance products that come online to assess how well they address cybersecurity risks was another topic identified by participants.
- Participants noted that research assessing what training will be needed for law enforcement as it encounters AVs would be beneficial.
- Research examining how the vehicles should be identified (via a registration or categorization of type) so that law enforcement can take appropriate action in the event of a crash was another topic identified by participants.

APPENDIX F

Breakout Session 5: Public Transport and Shared Mobility

ORGANIZERS

Gary Hsueh, *Arup, Lead Organizer*; Alejandro Henao, *National Renewable Energy Laboratory*; Chris Kopp, *HNTB*; Daniel Fagnant, *GM*; Elizabeth Machek, *U.S. DOT Volpe Center*; James Fishelson, *University of Minnesota*; Jean Ruestman, *Michigan DOT*; Katherine Freund, *ITN America*; Matthew Lesh, *Coast Autonomous*; Rachel Hiatt, *SFCTA*; Sam Lott, *Texas Southern University*; Scott Smith, *U.S. DOT Volpe Center*; Stanley Young, *National Renewable Energy Laboratory*; Stephan Parker, *TRB*; Susan Shaheen, *UC Berkeley Transportation Sustainability Research Center*; Taylor McAdam, *Fehr & Peers*; Thomas Cerny, *AECOM*; Tim Frisbie, *Shared Use Mobility Center*; Tom Voege, *OECD*; and Wendy Tao, *Siemens*

REPORTERS

Peyvand Hajian, *Stantec*; Martha Koch, *Arup*; and Taylor McAdam, *Fehr & Peers*

SESSION FOCUS

This 2-day session sought to address how vehicle automation technology can be harnessed across public transit and shared mobility services in order to provide mobility for all. Numerous pilot projects and partnerships have been forged between innovators and public transit agencies, municipalities, universities, and other groups over the past year. New research efforts are yielding insight into the potential impacts of privately owned AVs on transportation networks. Speakers discussed the experiences with different pilots and demonstrations, the results of recent research, and policy changes that would help support public transit and shared mobility services in an automated world.

The presentations from the sessions are available online at <http://www.automatedvehiclessymposium.org/avs2017/program/proceedings>.

DAY ONE SESSION SUMMARY

Quick Bursts A: National and International Policy Research

Elizabeth Machek, *U.S. DOT Volpe Center, moderator*

- Tom Voege, *International Transport Forum at the OECD (ITF-OECD)*. Voege discussed ITF's roundtable on government's role in regulating cooperative mobility systems and AVs. The primary outcomes of the roundtable were an understanding that guaranteeing the benefits of AVs requires regulation; current regulation stretches the existing framework, which will

be inadequate for automation at Levels 4 and 5; and internalizing transportation costs will be the best way to encourage shared mobility as an outcome.

- Vincent Valdes, *FTA*. Valdes discussed the FTA's MOD Sandbox grant program, focused on integrating MOD with the current model of public transit. The program was nonprescriptive, and cities proposed a wide range of ways to engage with MOD. He noted that there were far more applications (\$60 million) than available funding (\$8 million), highlighting the interest of cities to engage with MOD.
- Mark Norman, *TRB*. Norman highlighted the critical need for further research into shared mobility and AVs. He noted that the private sector is investing billions of dollars a year in research, and the public and academic sectors need to become more dynamic in their research roadmaps and more nimble in their fieldwork in order to keep pace. He suggested that re-evaluating the policy–research interface will help enable more and better research.
- Stephan Parker, *TRB*. Parker introduced TRB's research projects roadmap that has been guiding their AV research funding program for the past 3 years. The roadmap is extensive, but its particular value comes from its real-time flexibility. The roadmap is constantly changing to reflect new topics and research directions of research.
- Doug Gettman, *Kimley-Horn Associates*. Gettman discussed NCHRP Project 20-102 on technology readiness, safety, and operating policies surrounding AVs. He highlighted a number of issues that need to be addressed, including the ADA, the shift of transit employees from drivers to dispatchers, determining procedures for transit routes (e.g., speed), and managing the development of states' revised safety plans.

Discussion

- Participants discussed the need to retrain workers (e.g., as dispatchers) and collaborate with organized labor as transit vehicles begin to shift to AVs.
- Participants discussed the difficulty in the United States of implementing large new transit projects like the new PRT project proposed in Punjab. The government's limited control, and the difficulty of acquiring right-of-way, which is vital for transit reliability, can create larger barriers in the United States than elsewhere in the world.

State of Shared AV Developments

Susan Shaheen, *UC Berkeley Transportation Sustainability Research Center*

Shaheen presented the results of research on the current state of AV policy and programs. There are a number of pilots underway across the country for low-speed automated shuttles and conventional vehicles. At present, policy activity at the federal level focuses on safety and design. She noted that state legislative activity is inconsistent, with no best practices yet emerging. She suggested that local policy will probably increasingly address mixing of modes, taxation policy, and right-of-way issues.

Opportunities and Risks on the Road Toward Shared AVs

Sharon Feigon, *Shared Use Mobility Center*, moderator

- Bruce Schaller, *Schaller Consulting*. Schaller discussed a recent study of TNC use in New York City (<http://schallerconsult.com/rideservices/unsustainable.htm>), which revealed ride pooling options as unpopular and suggested that customers' seek to save time and reduce stress when using TNCs. He further suggested that there is an opportunity for cities to use their franchise authority, as they did with streetcars, to manage the new mobility systems. He noted that policy is critical to achieve a shared AV outcome.
- Alejandro Henao, *National Renewable Energy Laboratory*. Henao described the likelihood of zero-occupancy vehicles or deadheading issues with the rise of AVs. In light of this potential, he suggested that passenger miles traveled may become a more important assessment of vehicle use than VMT.
- Brian Sherlock, *Amalgamated Transit Union*. Sherlock addressed concerns about the disruption of the transit labor force by noting that transit will not suffer primarily as a result of AVs. Instead, he suggested that the biggest impacts will be from other related automated and AI technologies, which are already displacing much larger employment forces. He noted that a bigger issue for public transit is the lack of infrastructure spending. It is expensive to update it to the needed condition, and much more difficult to upgrade it for compatibility with new smart mobility trends.
- Steve Mortenson, *FTA*. Mortenson reviewed recent the FTA's assistance with bus technology projects. He noted that given the speed at which AV technology is advancing, the recent FTA focus is on foundational research highlighting use cases at various levels of automation: ADAS capabilities, low-speed automated shuttles, bus yard operations, and MOD services.

Discussion

Participants discussed potential causes for new mobility services' attraction for taxi and transit customers. Inefficiencies create by monopolies were suggested as a strong cause, although it was noted that monopolies apply primarily to private services. In the public realm, chronic underfunding has led to poor transit service in many areas. Participants suggested that new policies required by AVs offer an opportunity to foster a competitive environment that also serves users and agency needs.

Quick Bursts B: Updates and Lessons Learned: Sharing and Transit

Daniel Fagnant, *GM Moderator*

- Sharon Feigon, *Shared Use Mobility Center*. Feigon discussed the new technologies and public-private partnerships arising around shared mobility, which could be MaaS precursors. Choosing the right partner for public agencies is critical—it is difficult to negotiate how best to protect agency and user needs while figuring out how to be experimental. She noted that in the future, enabling cities and transit agencies to be mobility managers and brokers will be critical to ensuring the wide sharing of new mobility and AV benefits.
- Chris Cochran, *Pinellas Suncoast Transportation Agency (PSTA)*. Cochran outlined PSTA's partnership with Uber to provide first and last mile service, and emphasized the need to understand and address the regulatory issues that may arise as a result of federal funding,

including the ADA. He noted that local and state political support and a robust marketing campaign were critical to the success of the pilot.

- John Uργο, *AC Transit*. Uργο reviewed AC Transit's new flex service pilot, which replaces fixed-route service in a low-demand, low-performance area. The costs remained the same, although headways decreased from 45 to 30 min. He noted that most opposition to the project disappeared once the pilot started and the services headways were improved. He said that the future of flex service is likely a network service, although caution should be used, as total ridership did decrease.

- Leemor Chandally, *BestMile*. Chandally acknowledge the need for the current focus on vehicles, but she highlighted the increasing importance of supportive AV software such as BestMile, which provides fleet management. In building partnerships between the software, vehicles, and associated agencies, she noted that collaboration is vital to success, and that pilots should be seen as iterative projects.

- Neil Quarles, *University of Texas at Austin*. Quarles described research examining the benefits of automation and electrification of bus fleets, which revealed that full automation can drastically lower transit agency costs. It also indicated that electric buses are not cost-competitive with diesel buses but do offer other environmental benefits.

- Jonathan Matus, *Zendrive*. Matus discussed the need to understand the different cultural driving contexts in which AVs will operate (assuming mixed traffic). He noted that Zendrive collects driver data to help understand the relationship between risky driving behavior and crash prediction, a relationship supported by recent research conducted by the New York University.

DAY TWO SESSION SUMMARY

Treasure Island Case Study

Rachel Hiatt, *SFCTA*

Hiatt reviewed the traffic management plan for the new Treasure Island development in the San Francisco Bay. The plan includes a first-/last-mile automated shuttle solution to move residents between their homes and a transit hub. She highlighted that this pilot will be a key opportunity to see how the public interacts with an automated shuttle program. She noted that since the program will be implemented in the early phases of development, it offers an ideal environment for iteration. SFCTA is focused on integrating the shuttle program into the city's education and workforce development program.

Panel: Policy Implementation

Susan Shaheen, *UC Berkeley Transportation Sustainability Research Center*, moderator

- Emily Castor, *Lyft*. Lyft's AV strategy focuses on their software capacity, which can offer a marketplace and passengers to their AV-supplying partners. Castor underscored the need for strong uniformity at the federal level for AV safety, and the need for appropriate pricing and infrastructure changes (e.g., curb access) to ensure shared AVs.

- Frank Douma, *University of Minnesota*. Douma discussed recent research on transitioning from gas tax infrastructure funding to a distance-based fee. He noted that a

successful mechanism will be easily understood, paid, and collected; sustainable in the long-term, both as a scalable program and throughout technological changes; and acceptable to users concerned about privacy and equity.

- Mark Dowd, *University of California, Berkeley*. Dowd emphasized the importance of considering the interim stage of AV development—where we are now—and noted that how we regulate in the interim period will be critical for achieving an optimal future (shared) scenario. He also discussed the unsustainable current state of our transportation infrastructure, operations, funding, and planning, and that they must be addressed in order to provide better transportation service in the future.

- Doug Gettman, *Kimley-Horn Associates*. Gettman discussed areas of concern that need to be addressed in the future of AV transit: how ADA will be incorporated into all services and the implications of a new mobility paradigm on existing legislation, including the Civil Rights Act, Title VI, and Section 13C.

Discussion

- Participants debated the level and approach of policy needed at this early stage, which included discussions of how to balance regulations among local, state, and federal jurisdictions, at what point policy should be implemented, and the importance of data access.

- Participants discussed the need to understand what parking will look like during and after AV implementation, suggesting that parking infrastructure should be incrementally modified throughout the implementation period, and that new parking construction should be adaptable to future circumstances.

- Participants debated the appropriate amount of policy, and at what point it should be introduced. Positions included an emphasis on policy as a vital element in realizing the potential benefits of AVs; an argument for policy as supplemental to the marketplace; and the position that revealed consumer preference should be prioritized, with minimal policy intrusion.

Quick Bursts: Updates and Lessons Learned: Shared AVs

James Fishelson, *University of Michigan, moderator*

- Wessel van der Pol, *2getthere*. 2getthere recently expanded offerings from industrial automated pods to AVs for urban transit application. van der Pol highlighted the three settings for AVs: controlled, semi-controlled, and uncontrolled environments. Through participation on a number of projects as a vendor, 2getthere identified real estate developers and other sources of large investment funds as key collaborators in expanding pilots in the United States.

- Koorosh Olyai, *Stantec*. In reviewing current and future test programs in California, Canada, and New Zealand, Olyai noted that the interoperability of AVs (e.g., nationwide toll transponders) and the clear commitment of partners (both funding and operational) are critical to program success.

- Regina Clewlow, *Swiftly*. Clewlow discussed some fundamental building blocks that transportation providers need before MaaS can become a reality. She noted that transit agencies need to provide consistently accurate real-time data to passengers, as well as payment integration across services. However, many agencies' infrastructure for providing real-time data is insufficient and inaccurate, potentially losing customers. Swiftly recently helped support Baltimore in improving their data collection and dissemination infrastructure.

- Wendy Tao, *Siemens Mobility Division*. Tao outlined three major takeaways from Siemens' work in Berlin and with Swiss Rail: 1) without transit services, there can be no MaaS; 2) open data and common standards are good, but for MaaS to be successful, giving passengers reliable data is critical; and 3) legal elements may be harder to pin down than the technology. She also noted the importance of starting a pilot and scaling it up.

- Carlos Cardillo, *University of Nevada, Reno (UNR)*. Carlos Cardillo reviewed UNR's public and private coalition working toward bus automation. He emphasized the necessity of a "triple helix" coalition between industry, academia, and the government in their work—and the sharing of both physical and intellectual resources among the group.

Panel: Automated Mobility Districts

Stan Young, *National Renewable Energy Laboratory, moderator*

- Yuche Chen, *National Renewable Energy Laboratory*. Chen provided an overview of the U.S. DOE's efforts to model energy and environmental impacts of AVs in campus settings. Preliminary findings suggest that these systems induce more travel with less energy, but energy reduction is dependent on fleet characteristics, ridesharing levels, and service frequency. At this time, there is minimal literature, data, and simulation capability for Automated Mobility District impact or travel behavior analysis.

- Sam Lott, *Texas Southern University (TSU)*. Lott described a planned automated shuttle pilot for the university district in Houston. Service will be introduced on TSU's pedestrian thoroughfare, and will spread to increasingly complex environments. The focus is on a program that is deployable with today's technology, not cost-prohibitive, and that can fulfill ADA requirements. The size and nature of a campus environment is ideally suited to these needs.

- Brandon Newell, *U.S. Marine Corps (USMC)*. Newell described the USMC's unique needs on their bases: most private and official cars are rarely used, but provide the only means to leave the base; spouses and families also live on the base and have limited mobility. A proposed partnership with new mobility services aims to improve spousal employment opportunity, cost reduction for all by reducing the need for car ownership, and improved mobility across the base.

- Brad Thoburn, *Jacksonville Transportation Authority*. Thoburn described Jacksonville's plan for improving and expanding service on their Skyway monorail by replacing the current cars with automated shuttles. Replacing the tracked cars with AVs will enable the Skyway to expand its routes through street-level service. Thoburn noted that, although the total proposal costs less than the current system, Jacksonville is seeking a public-private partnership to share the project risk.

Discussion

- Thoburn responded to questions about the Jacksonville program concerning capacity issue and public pushback on elevated transport. He noted that the new automated shuttles might be smaller than the rail cars, but their more frequent service will neutralize any effect on capacity. Public pushback is expected to be minimal regarding elevated transport, as no new elevated track would be constructed; all geographic service expansion is expected to be served by bringing the Skyway down to grade.

- When asked about the evaluation framework for the public-private partnership, Newell emphasized that he wants to remain a facilitator and refrain from prescribing specific

actions. Instead, the experts—potential public and private partners—will propose their needs and objectives first.

- Lott fielded questions about the pilot program’s potential conflicts with pedestrians by noting that the value of mixing them into previously pedestrian-only spaces is the immediacy with which the pilot could get started, and that later phases of the pilot would remove the AVs from the plaza and run them on roads. Additionally, he reiterated that much of the research value of this program will be in observing interactions between pedestrians and AVs, providing opportunity for people to engage with the shuttle, and to see how the AVs will behave in such a dynamic environment.

- Participants discussed the importance of greenhouse gas and energy reduction in their programs. They noted that these are not the primary focus, but that the improved efficiency of their programs is anticipated as a longer-term benefit.

- Thoburn and Newell discussed two different approaches for balancing dedicated lanes for AVs with other modes, with Thoburn highlighting the integration of the Skyway into a broader complete streets network, and Newell noting that he plans to bypass dedicated lanes from the start.

SUGGESTED ACTION ITEMS

- Participants discussed possible follow-ups in NCHRP Project 20-102(02) related to laws, regulations, and the future of AV transit.

- Participants suggested ongoing tracking of the FTA’s transit automation roadmap and the MOD Sandbox projects.

- Exploring the messy, interim state of mixed use and how to reach a fully automated state was suggested by participants.

- Exploring how cities and transit agencies can take on roles as mobility managers and brokers, working in partnership with mobility providers was identified as a potential research project.

- Another research topic identified by participants was investigating the role and mechanisms for new and evolving mobility services to address societal issues, such as access and equity, ADA, Title 6, and environmental justice.

- Research to better understand thresholds of acceptable risks for cities and transit agencies was identified as a possible area for additional research.

- Participants stressed the benefits of continuing to share lessons learned from shared AV deployments.

APPENDIX G

Breakout Session 6: Trucking Automation *Key Deployment Scenarios*

ORGANIZERS

Johan Engström, *VTTI*; and Richard Bishop, *Bishop Consulting*

REPORTERS

Johan Engström, *VTTI*; and Richard Bishop, *Bishop Consulting*

SESSION FOCUS

The objective of this breakout session was to address key challenges and opportunities in the deployment of on-road truck automation. The first part of the breakout session began with presentations providing an overview of the current state-of-the-art in automated trucks and identifying key deployment issues. The session consisted of two panels with key stakeholders focusing on truck platooning and highway automation applications.

The second day was devoted to two deep-dive discussions. The first deep-dive discussion examined the deployment of automated trucking technologies with a logistics service provider (Martin Brower). The second deep dive discussed the application and deployment of Localizing Ground Penetrating Radar technologies to military vehicles and automated trucks.

PowerPoints of most of the presentations are available on the AUVSI website at <http://www.automatedvehiclessymposium.org>.

SESSION SUMMARY

Setting the Scene: State-of-the-Art and Key Deployment Issues in Automated Trucking

Johan Engström, *VTTI*, *moderator*

This introductory session included five presentations.

Truck Platooning: State-of-the-Art Review

Steve Shladover, *UC Berkeley*

Shladover noted that truck platooning is attractive for several reasons, including energy savings from aerodynamic drafting, more stable vehicle following dynamics, reducing traffic flow disturbances, and saving additional energy and emissions. Potential safety improvements represent another benefit.

Shladover suggested that platooning was not a recent invention, but rather the result of incremental research and development going back at least to the CHAFFEUR EU-funded project in the late 1990s. Recent key initiatives include the FHWA-sponsored Exploratory Advanced Research Program projects performed by California PATH and Auburn University and the European Truck Platooning Challenge.

Shladover described platooning at different levels of automation.

- Level 1 platooning service-orientated architecture (SoA). Shladover noted that there are several recent or ongoing research and development projects using L1 platooning. Further, Peloton Technology is planning a two-truck platooning product release. The major truck manufacturers are also considering platooning, but no announcements have yet been made.
- Level 2 platooning SoA. L2 platooning adds automatic steering control, which is likely necessary to enable shorter longitudinal gaps due to visibility limitations for the following driver at shorter distances. Shladover noted that multiple research projects have tested this approach, from CHAUFFEUR (1996–2004) to Konvoi, SARTRE, and Energy ITS. Some companies are conducting research and development on L2 platooning, including Daimler, Scania, and Uber.
- Level 3 platooning SoA. In L3 platooning, the driver can divert attention temporarily to other tasks, while remaining available to intervene when needed. Shladover suggested that, in general, L3 passenger car applications are likely to precede L3 heavy trucks.
- Level 4 platooning SoA. L4 platooning additionally assumes an ability to ensure a minimal risk condition without any human intervention while operating within its specified ODD. L4 platoon followers may be coupled behind a leader driven at L0, L1, or L2. He noted that in Singapore there are plans to implement L4 platooning for a 10-km route connecting two container terminals. Today, safety assurance state-of-the-art is not sufficient to support this level of automation for mixed traffic and highway-speed operations. Thus, in the more near term, L4 platoons may be limited to segregated truck-only lanes to simplify the ODD.

Robots on Our Roads: The Coming Revolution in Moving Freight State-of-the-Art: Highway Automation

Richard Bishop, *Bishop Consulting*

While the previous presentation focused on platooning specifically, this presentation addressed automated trucking more broadly. Bishop noted that there is an important distinction between automated driving and crash-avoidance technology: Crash-avoidance technology intervenes when things go wrong while automated driving technology automates the things we do right.

Bishop reviewed key factors affecting the trucking industry today, including driver shortages, hours of service, fuel cost, crashes, congestion, sustainability, trailer length–longer combination vehicles, and increasing home-delivery parcel volumes. He noted that automated driving technologies have the potential to address all of these.

Bishop discussed that key applications beyond platooning included, Traffic Jam Assist, Highway Pilot, Automated Movement in Queue, Automated Trailer Backing, and Parcel Delivery Automation. There are also several promising use cases for constrained environments such as trailer switching, mine hauling, and drayage and manufacturing/distribution in dispersed local sites.

In addition to platooning, Bishop reported that the main use case considered today for near-term deployment is highway exit-to-exit automation at Level 3-4. Examples of recent demonstrations include the Freightliner “Inspiration” truck, which features Highway Pilot (Level 3) and exit-to-exit driverless operations developed and demonstrated by Uber Advanced Technology Group. Additionally, several recent start-up companies are working on technologies for exit-to-exit driverless operations, including EMBARK and StarskyRobotics.

In summary, Bishop noted that the market demand for automated trucking applications is strong, with a significant potential ROI for the trucking industry. He reported that the industry is aggressively developing products and that synergies exist between the car and truck sides. He suggested that it is challenging for the government to keep pace with developments and, perhaps most importantly, there is a universal desire among all players to make automated driving a reality.

Caterpillar’s Journey to Automation and Lessons Learned

Michael Murphy, *Caterpillar*

Murphy described Caterpillar’s work on automated mining trucks, which began in the late 1980s, with the first generation research program continuing until the late 1990s. The second-generation program began in 2008 and continues to the present. The first commercial applications were launched in 2013. The program currently deploys 82 automated hauling trucks in several mines worldwide. Expansion to over 100 automated trucks will occur by the end of 2017. He reported that automation has led to dramatic cost reductions for mines. As an example, the Fortescue Solomon mine, which currently deploys about 60 automated trucks, reports the lowest operational costs in the world.

Murphy noted a key lesson learned is that what is being automated is not just the trucks themselves but the mining operations. The key motivation for automation is to increase the productivity through increased hours of operation. With respect to technology development, the key challenge was the validation and ensuring that all possible corner cases had been addressed. The validation and safety assurance also represented the main part of the development costs.

Murphy reported that there were also human factors issues that had to be addressed, especially issues related to the new skills required to operate and interact with the automated system and more general issues related to organizational change management.

Murphy noted that it was found that significant cost savings were obtained through more predictable operations. He reported that the automated trucking system has also proven to be very safe. During the 4 years of commercial operation, there have been no accidents resulting in injuries.

Key Results from the ITF-OECD Roundtable on Truck Automation

Tom Voege, *ITF-OECD*

Voege described the roundtable, which was chaired by Peter Sweatman (CAVita). Four discussion papers served as input to the discussion. Voege highlighted the following key conclusions from the roundtable.

- Autonomous trucks are likely to be the first use case of AV technology. There is a strong business case for automating long-distance freight operations on motorways, which additionally represents a relatively benign and less complex environment for implementing automation.

- Harmonized regulation is more important for autonomous trucks than other AVs. Autonomous trucks are more likely than other vehicles to cross (national and state) borders, and are thus susceptible to multiple regulatory frameworks applying to a single trip.
- Existing regulations can accommodate AV technologies up to a point, but this becomes increasingly challenging when moving up to higher levels of automation. Industry generally prefers adapting existing regulations to creating new frameworks locking in a standard that is too high or too low.
- Stretching existing regulatory frameworks has its disadvantages and limits. Stretching the interpretation of existing regulations is a blunt instrument and unintended consequences are likely since the regulation was not originally intended for autonomous trucks.
- Truck automation will create disruptive employment issues and have substantial labor impacts. Job losses of 1 million people in Europe and in North America are possible as a result of advanced AV technology.
- There is a strong potential for data-driven approaches for regulation and enforcement.

Key Deployment Issues in On-Road Truck Automation: Public Policy, Regulation, and Market Structure

Laurence O'Rourke, *ICF*

O'Rourke discussed the results from the project NCHRP 20 102 (3) *Challenges to CV and AV Applications in Truck Freight Operations*, which is available at <http://www.trb.org/Main/Blurbs/175965.aspx>.

A patchwork of state laws for AVs currently exists in the United States. At the time, 18 states had enacted AV laws and four states have chosen to use executive orders to outline a policy toward AVs. States also use different definitions of AVs and have different rules for testing and using AVs. In the case of platooning, the allowable following distance for trucks is dealt with differently in different states. Increased harmonization is needed.

Current FMVSS regulations assume that a driver may be a barrier to novel designs. FMVSS exemption caps have recently been increased from 2,500 vehicles to 100,000 vehicles, which allows manufacturers to experiment with more novel designs for more HAVs, although they still need to demonstrate that the designs are safe. The FMCSA hours-of-service regulations, security, and privacy are other key areas that need to be addressed by regulation.

Market structure affects the opportunity for autonomous trucks. Large private fleets, with homogeneity in their tractor OEM and predictable routes, large truckload carriers, and less-than-truckload carriers operating long-haul trucks on fixed routes between terminals may gain the best savings from platooning. Firms operating long-haul trucks with team drivers may gain large labor productivity benefits from highly automated trucks. Some labor productivity benefits will depend on hours-of-service rule changes. Almost all carriers expect a payback on investment in truck automation technology in 3 years or less.

A key problem in the trucking industry is driver attrition, with large truckload carriers experiencing a 74% turnover rate for drivers in the first quarter of 2017. Automated driving may offer an improved working environment for the driver in large long-haul fleets. Automated trucks could be very valuable if they help to reduce driver turnover.

PANEL 1: DEPLOYMENT OF PLATOONING

Richard Bishop, *Bishop Consulting, moderator*; Bill Kahn, *Peterbilt, panelist*; Andrew Pilkington, *Bendix, panelist*; Steve Boyd, *Peloton, panelist*; Osman Altan, *FHWA, panelist*; Max Fuller, *US Xpress, panelist*; John Schroer, *Tennessee DOT, panelist*; Richard Makowski, *Ohio DOT, panelist*; Charlie Collins, *Arkansas House of Representatives, panelist*

The panel began with a round of introductory statements from the panelists, who expressed a shared belief in the value of platooning technology and the feasibility of near-term deployment. Below is a summary of some of the key topics addressed during the panel discussion.

Platooning Business Cases and Ways to Stimulate Deployment

Panelists commented that fuel savings is the key factor driving the platooning business case. It was noted that fleets typically require payback on their investments within 12 to 18 months and that it was also important to keep in mind the additional investments needed for platooning such as driver training and extra maintenance. Some key ways to stimulate platooning noted by panelists were changing and harmonizing regulations and business models involving reduced insurance rates. It was also suggested that publishing results and making data available contribute to faster deployment. From a carrier perspective, it was suggested that deployment is best conducted in a stepwise, iterative, fashion, beginning with a few vehicles in a real fleet, identifying issues and taking the data back to the manufacturer to fix any identified problems.

Platooning Uptake

Several panelists also suggested that the uptake of platooning might initially be slower than expected but then may accelerate faster than expected, citing Bill Gates' comment that people typically overestimate technology adoption in the short term but underestimate it in the long term.

Safety Assurance

Safety assurance was identified as a key topic by all panelists. OEMs, suppliers, and technology companies need to work together to ensure the safety of platooning applications by means of simulation, track tests, and on-road field tests. Panelists further identified a number of specific issues that need to be addressed for platooning, such as how to deal with different braking capabilities of the vehicles in the platoon. It was pointed out that there is a strong need for novel testing and simulation methodologies to address these types of issues.

Effect on Labor

The issue of loss of driver jobs due to higher levels of automation was discussed by panelists. Contrary to the conclusions from the ITF-OECD Roundtable presented earlier, the panelists did not believe that that platooning, or automated driving in general, would have a dramatic impact on labor, at least not in the short term. Rather, it was suggested that automated driving may be a way to improve the drivers' work situation and hence attract good drivers. As mentioned earlier, a key issue today in the trucking industry is the shortage of drivers, in particular good drivers.

Public Acceptance and Trust

It was suggested that educational campaigns would be important to foster public acceptance of platooning and other AV technologies.

PANEL 2: DEPLOYMENT OF HIGHWAY AUTOMATION AND OTHER NON-PLATOONING AV APPLICATIONS

Bob Denaro, *ITS Consulting, moderator*; Franklin Josey, *Volvo, panelist*; Alden Woodrow, *Uber ATG, panelist*; Kelly Regal, *FMCSA, panelist*; Greg Larson, *Caltrans, panelist*; and Bryan Jones, *Martin Brower, panelist*

As in the previous panel, panelists expressed strong interest in AV technologies. They further suggested that technology was ready, at least for some initial AV applications, and that the key challenge was now to get technologies to the market. Below is a summary of some of the key topics addressed in the panel discussions.

Benefits of Lower Level Automation

While higher levels of automation have clear benefits in terms of productivity and reductions in operational costs, the panel discussed lower-level automated trucking applications where the driver still needs to be involved in the driving. Panelists noted that these applications are expected to have numerous safety benefits, beyond those possible to achieve with traditional active safety systems. Safety was a key concern for all the panelists. Panelists also expressed interest in reducing the environment impacts from truck emissions. Environmental stewardship was noted as good for business and the right thing to do. Panelists noted that Level 1 and Level 2 truck platooning was expected to result in fuel savings and reduced environmental impacts.

Key Hurdles for Deployment

Panelists discussed several issues related to deployment, including public perception and the need to harmonize regulations for testing and deploying AV functions. It was suggested that deployment of automated driving technologies would benefit from being conducted in a stepwise manner, with a focus on safety assurance, which was viewed as a critical issue, especially in the deployment of higher levels of automation. Brand trust was noted as important to carriers and their shipping clients. The importance of public perception was also noted. Several panelists emphasized the need for virtual testing and simulation. Interest was also expressed in exploring the potential of AV technologies to support inspection, repair, and maintenance.

Public Acceptance and Trust

It was suggested that one key problem is the common perception, often conveyed by media, that Level 5 automation vehicles will suddenly appear on streets. Participants noted that it was important to convey a more nuanced view and focus on explaining the benefits of AV

technologies to the public. It was also suggested that demonstration activities may be a way to raise public awareness and gain acceptance.

Levels of Automation

Panelists discussed whether deployment of truck AV would move gradually from Level 1 to Level 5, or whether there will be a distinct jump between Levels 1–2 and Levels 4–5, thus skipping Level 3. Panelists expressed mixed reactions on the speed of deployment. Panelists noted that professional driver training should focus on the new role of the driver, which may help in attracting new drivers to the industry.

Street-Level Automation

Panelists discussed street-level automation in more urban settings. It was pointed out that this environment is very challenging with drivers undertaking numerous tasks that are difficult to automate. The potential for exclusive lanes for automated trucks on roads connecting to the Port of Long Beach in California was noted by one panelist.

WRAP-UP, DAY ONE

Richard Bishop, *Bishop Consulting*

Bishop summarized some of the major points discussed by speakers and panelists. He noted that trust in AV technologies, both from the customers and the public, was a key factor affecting deployment, as was safety assurance. Additionally, since the ROI from automation depends on the specific type of operations being automated, knowing the customer and their specific operations when deploying AV technologies was critical. The fact that key deployment factors may differ between operating environments, plus additional complicating factors such as organizational issues (e.g., related to changing roles of drivers) and regulatory issues at the state and federal levels, makes trucking automation deployment a multidimensional problem. These factors make it difficult to predict the future of automated trucking.

DEEP DIVE 1: TRUCKING AUTOMATION: THE FUTURE OF SUPPLY CHAIN TRANSPORTATION

Richard Demato, *GoodOps, moderator*; Divya Demato, *GoodOps, moderator*; and Bryan Jones, *Martin Brower, panelist*

This deep-dive session discussed the potential application of automated driving technologies to support the operations of a specific carrier, Martin Brower. Three general questions were addressed were How will automated driving impact operations? How will it be rolled out? What are the benefits/downsides?

Martin Brower is a global business with 1,200 truck operations, mainly in the food logistics domain. The main priorities of their customers are food safety, quality, brand trust, and

sustainability. Approximately 50% of the shelf life of cold food is lost during transit so automated driving has a great potential to increase the efficiency of the cold food supply chain.

The specific use case discussed in the session represented long haul, single product, two truck, single-temperature trailers, driving mainly on Interstate freeways with trip lengths of 400 to 600 mi. The automated driving applications of main interest was platooning and higher-level exit-to-exit operations on Interstates with the goal of increasing efficiency and productivity. The moderators mentioned that they are planning to conduct field studies on this use case. Several state DOT representatives in the audience offered their support for such tests.

Some of the key issues addressed during the discussion included the following:

- Will advanced driving change regulations for hours-of-service? When does the driver count as a driver from the hours-of-service perspective? These questions have an impact on driver productivity.
- What degree of driver training will be needed when deploying automation?
- How will the adoption of automation technologies differ between different types of carriers, including large fleets and owner-operators?
- What strategic partnerships need to be developed for successful deployment of automated driving technologies?

Due to lack of time, a second use case representing operations from a distribution center to a delivery point was not undertaken.

DEEP DIVE 2: LOCALIZING GROUND PENETRATING RADAR FOR ROBUST AUTONOMOUS LANE KEEPING

Byron Stanley, *MIT Lincoln Laboratory, moderator*; David Cist, *Geophysical Survey Systems, Inc., moderator*; and Babak Memarzadeh, *Geophysical Survey Systems, Inc., moderator*

This session addressed a specific enabling technology. A key challenge for automated driving systems is precise localization on the road. Traditional onboard sensors such as GPS, radar, and cameras, are challenged by a variety of adverse conditions such as limited or changing features, covered surfaces, surface feature changes, obscuring conditions, and interference/blinding. Speakers in this session presented and discussed ground penetrating radar (GPR) as a technology for enhancing localization robustness in AV applications. GPR is based on 3D mapping of existing underground structures that, given that these structures are persistent over time, may be used for precise localization.

The speaker noted that the technology has been demonstrated on autonomous military ground vehicles deployed in Afghanistan, and under SUVs operating in snow, rain, and at speeds of up to 65 mph. It was suggested that GPR might have a great potential to add robustness as an additional sensor supporting autonomous lane keeping due to its status as an independent method of localization. However, some key challenges remain. For example, depth of penetration for the map depends on the nature of the soil, which differs between regions, though the resulting limited character may be resolved by comparing larger volumes of data. Additionally, the current technology has not been demonstrated at speeds above about 65 mph, though expectations are that, with an increased ground sample rate, there will be no issues. It was suggested that trucking

is a good initial fit for the technology, as the current form factor and moderate volume production costs are likely within the desirable range. More details on the technology are provided in the PowerPoint slides on the AVS website.

SUGGESTED ACTION ITEMS

Based on the presentations and panel discussions, the following items were identified as key to the successful deployment of automated trucking.

- Stepwise deployment and validation in real operations with carriers.
- Safety assurance: collect field data and combine with track testing and simulation.
- Driver training and education.
- Establishing interaction between stakeholders and new strategic partnerships.
- Educational campaigns and demonstrations for the public to establish awareness and trust of automated driving technologies.
- Harmonization of state regulations.

APPENDIX H

Breakout Session 8: Urbanism Next Workshop *Automated Vehicle's Effects on Urban Development*

ORGANIZERS

Nico Larco, *Department of Architecture, Sustainable Cities Initiative, University of Oregon*, and Caroline Rodier, *Institute of Transportation Studies, University of California, Davis*, organizer

REPORTERS

Nico Larco, *Gerry, Tierney and William Riggs*

SESSION FOCUS

While there has been a lot of work on AVs, to date it has primarily focused on technological aspects and deployment. Focusing on the urban design implications or identifying and addressing potential secondary impacts has been given less attention. These secondary implications may end up being the largest limitations to the successful rollout of AVs particularly with regard to the disruption it may create.

This breakout session examined the potential impacts of AVs on e-commerce and the sharing economy, as well as on the city form, design, and development. The Urbanism Next breakout session worked to frame the technology as inextricably linked to e-commerce and sharing.

The simultaneously emerging technologies of AVs, e-commerce, and sharing economies have interconnected aspects with the potential for major effects on cities and society at large. AVs are not simply a transportation issue. More precisely, they have the potential to effect land use, land valuation, development sprawl, social equity, labor, and urban vitality. Planners, designers, and policymakers need to understand these effects to minimize disruptions.

SESSION SUMMARY

The breakout session began with high level presentations addressing secondary impacts and potential mitigation of issues such as the effects on land use, district design, sprawl, mode choice, parking and street design. Following these presentations, participants examined two prototypical sites. The goal was to consider the pressures the sites will face as a result of emerging technologies and how they might adapt.

The sites were based upon two existing areas in Portland, Oregon, however, they were meant to represent typical conditions around the country. The first site was a pre-World War II [1920s] streetcar suburb with a commercial neighborhood and surrounding residential areas. The second site was a post-war [1970s] autocentric suburb with a big-box strip mall surrounding

residential development. Participants were given a brief description of the sites and encouraged to consider both optimistic and pessimistic scenarios of how they might develop, change or adapt over time.

- Pre-war streetcar suburb primary existing features include:
 - Typical development grid, walkable, well served by bus and light rail, with a major arterial cutting through the suburb.
 - One-to-three story commercial core surrounded by single-family homes.
 - The commercial development primarily serves the neighborhood, with a few regional retail draws.
 - There is a substantial amount of surface parking and a few parking structures, which present infill development opportunities.
- Pre-war streetcar suburb potential change/adaptation includes:
 - Parking reductions of up to 90% in a shared AV environment will create opportunities for infill development; this is compatible with enhanced transit and a shared AV environment;
 - Some of the freed-up parking lots could be repurposed to neighborhood parks;
 - Regional serving “artisanal” retail is well suited to and served by shared AV and enhanced transit; and
 - Street diet will enhance walkability and bike use.
 - Participants suggested that the overall future outlook is good.
- Post-war big-box strip mall suburb primary existing features include:
 - Development is focus on a big-box strip mall, located along major arterial, with large parking areas, and a mix of local and regional commercial/retail.
 - The mall is surrounded by mostly enclaved single access “loops-and-lollipops” single-family home developments.
 - These developments are auto-oriented, with poor to nonexistent pedestrian or cycling amenities, and minimally served by transit.
- Post-war big-box strip mall suburb – potential change/adaptation:
 - AV-induced parking demand reductions, combined with e-commerce, could provide opportunities for infill development at the current big-box strip mall; increased density will create opportunities for enhanced transit.
 - Vacated and reduced footprint big-box retail will require catalyst tenants or activities to prevent blight, entertainment or cultural focus perhaps.
 - Online retail reduces municipal sales tax revenues generated by vacated big-box retail outlets. Cities need to find alternative tax sources.
 - Major opportunities exist for street diets to enhance walkability and bike use.
 - Participants suggested that the overall future outlook is mixed with some good and some bad due to e-commerce impacts on malls.

Participants also discussed the following topics:

- Maintaining an overall focus on community goals is important. The deployment of technologies needs to address improving the quality of life, ensuring social equity, taking care of all residents’ needs, and creating opportunities for commerce. Consideration of emerging technologies within the context of these goals and filters should be encouraged.

- The potential benefits to be derived from an AV environment need to be identified in a holistic manner and directed towards the benefit of all. While the transportation efficiencies are important, consideration also needs to be given to the downstream impacts of AV development and deployment, which will be “game changers.” The potential exists to fundamentally change so many aspects of how people shop and work.

- It is important to consider AV development and deployment in a holistic manner. Helping the technology community understand the importance of the non-technical issues, and the importance of translating possible implications to the public was discussed. Obtaining a better understanding of how people will interact with these vehicles is needed.

- Planners and policymakers need to understand who the stakeholders are and engage them in a meaningful manner. Bringing a broader discussion of the possible secondary impacts would be beneficial, including considering social equity and spatial justice issues.

SUGGESTED ACTION ITEMS

- Encourage TRB and AUVSI to continue this dialogue at the 2018 AVS and other appropriate conferences.

- More research should be conducted under umbrella scenarios, such as the EU’s Mobility4EU initiative or the U.S. DoE’s Urban Structures research area.

- Encourage local policy makers and planners to engage in the dialogue. Promote broadening coordination across agencies at the municipal, state, and national levels.

APPENDIX I

Breakout Session 9: Effects of Vehicle Automation on Energy Usage and Emissions

CO-CHAIRS

Avi Mersky, *CMU*; and Zhenhong Lin, *Oak Ridge National Laboratory*

ORGANIZERS

Amitai Bin-Nun, *Securing America's Future Energy*; T. Donna Chen, *University of Virginia*; William Chericoff, *Toyota*; Jia Hu, *Federal Highway Administration*; Natarajan Janarthanan, *Washington State DOT*; Paul Leiby, *Oak Ridge National Laboratory*; Xiao-Yun Lu, *University of California, Berkeley*; Don MacKenzie, *University of Washington*; Mathieu Joerger, *University of Arizona*; Jimmy O'Dea, *Union of Concerned Scientists*; Constantine Samaras, *CMU*; Tom Stephens, *Argonne National Laboratory*; Zia Wadud, *University of Leeds*; Jacob Ward, *CMU*; and Guoyuan Wu, *University of California, Riverside*

REPORTERS

Zhenhong Lin, *Oak Ridge National Laboratory*; and Avi Mersky, *CMU*

SESSION FOCUS

This session focused on the potential effects of automation on the energy of vehicle travel, at both the disaggregate and aggregate levels. Speakers and participants discussed underlying factors, including the value of TT, fuel type, charging infrastructure for automated EVs, and driving behavior. Policy implications, including the fuel economy treatment of AVs, relationship between automation and electrification, and taxation were also discussed. The PowerPoints for most of the presentations are available on the AUVSI website at <http://www.automatedvehiclessymposium.org/avs2017/program/proceedings>.

SESSION SUMMARY

- Joshua Auld, *Argonne National Laboratory*. Auld presented results of POLARIS simulations of CACC-enabled personal vehicles, which indicated that estimated changes in VMT and energy use are sensitive to the value of TT and how CACC is adopted by heterogeneous consumers. Research needs suggested by Auld included examining consumer adoption of automation technologies, developing reliable estimates of TT value, and conducting similar analyses beyond privately owned CAVs.

- Amitai Bin-Nun, *SAFE*. Bin-Nun presented a framework for assessing the impacts of AVs on travel demand by segmenting National Household Traffic Survey data by population density and trip distances. He suggested areas with high density and short trips were sweet spots for urban AVs. He described estimated induced VMTs by AVs for different demographic cases. He examined a geofenced urban taxi scenario. He estimated reduction of household vehicle ownership due to urban AV taxi.
- Jeff Gonder, *National Renewable Energy Laboratory*. Gonder presented an approach to national-level VMT and energy use estimation by rolling-up vehicle-level energy consumption results under different road conditions over all U.S. road segments. This approach considers CACC penetration scenarios with conventional powertrains and with high EV adoption. The approach used data on vehicle miles distribution by road type and vehicle type, and assumed speed increases due to automation.
- Zhenhong Lin, *Oak Ridge National Laboratory*. Lin described the development and preliminary results of the MA3T-MC model that reflects the DOE Future Mobility Framework; Heterogeneous consumers described by correlated and mobility-relevant attributes. He noted that the results suggested synergy between vehicle automation and EVs fewer plug-in EVs (PHEVs) because automation is more valuable for battery EVs (BEVs) (range extension) and gasoline vehicles (energy savings) and less valuable for PHEVs (energy savings). He noted that consumer heterogeneity is important, as some consumers, including modest drivers, care little about range extension from automation.

Discussion

Topics discussed by participants included the impact of added new travelers, the impact of CAV following behavior on link capacity, the amount of cooperative driving needed for increased capacity, infrastructure investments, and traffic control trade-off such as signal versus roundabout.

- Xiao-Yun Lu, *University of California, Berkeley*. Lu discussed truck CACC fuel economy testing. He described test results for three connected trucks and the aerodynamics effect of CACC. The trucks were Class 8 semis with box trailers, underskirts, and boat tails. A fuel consumption reduction of approximately 7% for the second truck to 10% for the third truck was noted.
- Andrew Eilbert, *U.S. DOT*. Eilbert discussed evaluating energy and emissions impacts of CACC through traffic microsimulations using PTV VISSIM, 10-Hz input to MOVES. The results were reported by road link and MOVES operating modes. Traffic data from the Massachusetts DOT was used.
- Jia Hu, *Federal Highway Administration*. Hu discussed road test and hardware-in-the-loop simulation results of CAV eco-driving algorithms on rolling terrain. The project observed 10% to 14% fuel savings in hilly terrain. Both gear-only and integrated optimization were considered.
- Liang Hu, *Iowa State University*. Hu described simulations of 15 cars in a lane equipped with CACC using OBD-II data. Both gasoline and EVs were analyzed based on the Urban DynaMomentum Driving Schedule. The results indicated that energy savings were sensitive to the choice of a car-following model. The VT-Micro model was used in the project.

- Morteza Taiebat, *University of Michigan, Ann Arbor*. Taiebat discussed the reduction in unoccupied vehicle VMT and GHG emissions for a Robotaxi fleet based on GPS trajectory data of approximately 500,000 trips by 12,000 vehicles over 3 days. The number and the location of chargers were considered. A 50% reduction in unoccupied vehicle VMT could be realized if trip chains were optimized. The resulting GHG emissions reduction was significant if vehicles were converted to BEVs and even if the Beijing coal-dominating grid is considered. Empty vehicle VMT was found to be more sensitive to station number than to station locations.
- Lei Zhu, *National Renewable Energy Laboratory*. Zhu discussed the potential fuel savings from green routing based on trip-level data. Vehicle speed, road type, and grade were considered. Fuel savings of a few percent were found for a subset of trips. The trade-off between fuel savings and time cost were considered. Both can be reduced by better route choice.
- Zhuoyi (Tony) Zhang, *University of Virginia*. Zhang described the effect of using shared autonomous EVs in facilitating first- and last-mile connections to transit services. Data from 200 vehicles were used, which considered their in-use status and occupancy. Tukwila station in Seattle was used for the case study. The results included the percentage of trips served by hour of the day, with 92% on average and fairly even shares of occupancy from 1 to 4.
- Matthew Barth, *UC Riverside*. Barth discussed a literature review on the benefits of vehicle automation, including safety, mobility, and the environment. The review found that most papers focus on the safety benefits of AVs, but a few consider tuning automation to achieve co-benefits. He suggested that improved control (dynamic parameter tuning) could improve the synergy between safety, mobility, and environmental effects.
- Avi Mersky, *CMU*. Mersky described optimizing EV charging station locations for EVs of different levels of automation. The analysis found that high levels of automation can make it easier and cheaper to use or own EVs, since Level 4 (park and walk) or 5 AVs (park anywhere) could drive themselves to a charging point. Level 4 would not offer the advantages of Level 5 automation. A Level 4 vehicle may require parking closer to a public charge station and some walking by the passenger, whereas a Level 5 AV could deliver a person right to their destination and then drive itself to a charger. Level 5 would allow much more flexibility in moving charging demand to off-peak periods. The cost of EV supply could be reduced by approximately 75% (\$1.75 million to \$500,000) at Level 5. Further, optimized EV infrastructure for AVs could smooth charging demand since one charger can be used multiple times.
- Therese Langer, *American Council for an Energy-Efficient Economy*. Langer discussed the eligibility of vehicle automation and connectivity for credits in fuel economy and GHG regulation. He noted that credits have been proposed based on smoother driving, congestion reduction, and promoting electrification and sharing. He described possible principles for off-cycle credit eligibility and suggested moving to real-world emissions as a preferred approach for capturing benefits of AVs.
- **Jonathan D. Rubin**, *University of Maine*. Rubin discussed taxation strategies to promote sustainable energy outcomes with CAVs. The strategies considered the optimal/efficient tax concept with income consideration. He suggested that the optimal fuel tax should be higher than the current level if the external costs from the Environmental Protection Agency and DOE are considered. He discussed taxing fuel versus miles. He suggested that a fuel tax should be higher for AVs than manual vehicles, while a VMT tax should be lower for AVs. The lower AV accident rate means lower external cost and justifies lower optimal tax.

SUGGESTED ACTION ITEMS

- Participants noted the need to continue ongoing active research on estimating increased or decreased energy consumption from CAVs with a goal of developing comprehensive estimates for different driving scenarios focused on road segments, driving style, vehicle types, traffic conditions, weather, and other variables.
- Participants suggested the need to continue the preliminary but important discussion on policies related to CAVs based on their internal or external effect on energy and emissions. Considering how to leverage policies to increase the benefits among safety, mobility, and energy/environment was noted as beneficial.
- Participants noted the need to expand research on the synergy between CAVs and EVs, including considering the charging infrastructure for automated EVs.
- Participants noted the need to continue and expand the research on modeling market adoption of CAVs. The results of this research may affect many other issues associated with CAVs, including safety, congestion, energy, and emissions effects

APPENDIX J

Breakout Session 10: Data Sharing Models and Policy

ORGANIZERS

Shawn Kimmel, *Booz Allen Hamilton*; Anita Kim, *USDOT Volpe Center*; Ginger Goodin, *Texas A&M Transportation Institute*; Baruch Feigenbaum, *Reason Foundation*; Richard Mudge, *Compass Transportation and Technology*; Amitai Bin-Nun, *Securing America's Future Energy*; David Perlman, *USDOT Volpe Center*; and Carl Andersen, *USDOT Federal Highway Administration*

REPORTER

Tammy Trimble, *VTTI*

SESSION FOCUS

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, performance and operations, and infrastructure. The following questions helped focus the decision during the session.

- What are the value exchanges between various public and private entities that incentivize sharing?
- What types, formats, and granularity of data are needed to achieve the desired benefits?
- How can public agencies best prepare data infrastructure and policy to be ready for AVs?
- How can AV data be shared while protecting proprietary and liability concerns?
- What data standards are needed to support data sharing, and what is the role of the public and private sectors in developing and enforcing these standards?

PowerPoints of most of the presentations are available on the AUVSI website.

SESSION SUMMARY

The session consisted of two presentations to set the stage followed by two panels. Interactive discussions followed each panel. The session concluded with a discussion of the major themes covered during the discussion and suggested action items.

PANEL 1: INTRODUCTION TO DATA SHARING ISSUES AND ACTIVITIES

Shawn Kimmel, *Booz Allen Hamilton, moderator*

Speakers in this panel presented an overview of the session goals and a brief background on data sharing models and policy to set the stage for the session. Speakers presented a review of the current data issues and an update of related activities.

Steve Sill, USDOT ITS JPO, Standards Program, discussed the Standards Roadmap activities as it relates to data, including a report from the Monday auxiliary session on technical standards prioritization.

Ariel Gold, USDOT ITS JPO Data Program, discussed existing and proposed efforts to support AV implementation through data management tools and guidelines.

Key ITS JPO program efforts discussed during this panel along with links to relevant resources are noted in the following.

- ITS Strategic Plan 2015–2019 includes:
 - Outlines the direction and goals of the U.S. DOT’s ITS Program.
 - Provides a framework around which the ITS JPO and other department agencies will conduct research, development, and adoption activities to achieve them.
- ITS JPO Data Program (Fact Sheet) objectives include:
 - Increasing adoption of efficient and secure data sharing architectures within ITS deployments.
 - Sharing ITS research data to fuel third-party research and application development.
 - Operationalizing privacy-by-design principles.
 - Providing strategic direction for the ITS community.
 - Program resources include:
 - ITS Operational Data Environment,
 - The ITS Research Data Exchange,
 - ITS research data focused on road weather, and
 - The ITS Situation Data Clearinghouse and Warehouse (SDC/SDW).
- ITS Standards Program includes:
 - The National ITS Architecture which provides a master blueprint for building an integrated, multimodal, intelligent transportation system.
 - The International Standards Harmonization’s purpose to establish common architectures, standards, policies and other critical processes that benefit from being as similar as practical across regions.
 - ITS Standards and U.S. DOT ITS Research Initiatives (including the Connected Vehicle Standards).
- U.S. DOT ITS Architecture, Standards and Harmonization Program (Fact Sheet).

- Architecture which provides a framework to guide planning and interoperable deployment of ITS and identifies interfaces for standardization.
- Standards that defines interfaces within architectures to enable required interoperability and support efficient deployment.
- International harmonization seeks to leverage global resources and expertise to
 1. Maximize commonality of ITS deployments;
 2. Share labor resources; and
 3. Access best-available expertise in order to facilitate ITS deployment and efficient markets.

PANEL 2: SAFETY AND PERFORMANCE DATA

Shawn Kimmel, *Booz Allen Hamilton, moderator*

This panel explored issues associated with the types of data that can improve overall transportation system safety and support safety assurance. Example types of data include driving scenarios, event data recorders, lessons learned, aggregated safety performance data, test cases, and disengagement reports.

Panel

David Kidd, *Senior Research Scientist, Insurance Institute for Highway Safety (IIHS)*; Jim Adler, *Vice President of Data, TRI*; Bob Lange, *Vice President of Vehicle Engineering, Exponent*; and Jonathan Weinberger, *Automotive Information Sharing and Analysis Center (Auto-ISAC)*.

General Discussion

1. The consistent, reliable, and mandatory collection of publicly available information is necessary for evaluating the safety of automated systems.
2. How safe is safe enough? The bar for AVs is high because human drivers are generally really good.
3. Communities need to come together to discuss the issues and work on solutions. Groups such as the Auto-ISAC and IIHS can serve as models for information sharing, may help to address cultural resistance to sharing data, and may provide incentives for otherwise reluctant partners to participate.
 - When it comes to sharing data, in addition to liability, privacy, and antitrust concerns, OEMs and suppliers face competitive concerns.
 - Further, these partnerships may help nondata native groups to work to become more data-native. This will help to reduce friction around datasets so when asked for data by government for a specific purpose they are able to respond. By beginning sooner, rather than later to think about data sharing, there is increased opportunity to determine protocols and tools for sharing data.
4. There is a need to begin thinking about what issues can be resolved in the near-term via policy solutions versus those issues that will require additional research and testing before

policy may be formulated. To facilitate the necessary supporting data, there must be an exemption process to allow for testing.

5. The current state of developing policy is in flux, and solutions may not be permanent. May not want to define what data must be but rather the timeframe for collecting data.

6. Are we paying enough attention to what data we want to collect, how to collect it, and how it will be used?

- There is a need to begin thinking about what variables should be collected via EDRs to help determine crash liability and circumstances and to understand operational domain limitations.

- In determining which variables are most important and will lead to the greatest safety benefits, thought also should be given to standardization of these variables.

- There is a shifting standard of privacy and acceptability. Some privacy concerns may be mitigated over time if users believe that they are getting value in return for what they are giving up and if they do not believe that the data is being misused by those in a power position.

The Commission on Autonomous Vehicle Testing and Safety, a project of Securing America's Future Energy's Autonomous Vehicles Task Force, has provided seven recommendations for creating public confidence in AV development, testing, and early deployment and establishing a preregulatory agenda (read the commission's report). The seven recommendations are

Part 1. Assuring Public Confidence

1. The commission recommends that AV providers move to onroad testing and deployment only after they are confident that the vehicle's performance is as safe as the average human driver, accounting for backup drivers, speed restrictions, geofencing, and other safety measures.

2. The commission encourages AV providers to create safety milestones for AV development. The commission further encourages public disclosure of achieved milestones and accompanying validation.

3. The commission encourages developers to deploy redundant layers of technology to increase safety beyond any minimum required standard.

4. The commission encourages developers to clearly define and effectively communicate autonomous features including their limitations.

Part 2. Steps Toward and Industry-Driven Regulatory Framework

5. The commission encourages AV providers to formally collaborate through a technical data consortium to accelerate AV learning and safety through shared, anonymized information.

6. The commission recommends that industry formulate objective, practical, and quantitative metrics for measuring AV safety.

7. The commission recommends that any future framework for regulating AVs rest on a modern foundation reflecting the advanced software-driven nature of vehicle automation.

Additional noted resources include:

- IIHS Automation and Crash Avoidance.
- *How Safe is Safe Enough?* Gill Pratt, 2017 Consumer Electronics Show (CES2017) Press Conference.
- Automotive Cybersecurity Best Practices from the Auto-ISAC.

PANEL 3: OPERATIONS AND INFRASTRUCTURE DATA

Anita Kim, *U.S. DOT Volpe Center, moderator*

This panel explored the various local, state, federal, and international models for sharing data that can improve situational awareness, efficiency, and resource allocation for AVs and agencies alike. Example types of data included: work zones, signal phase and timing, road closures, weather, incidents, and traffic conditions.

Panel

Shailen Bhatt, *Executive Director, Colorado DOT*; Scott Marler, *Director of Traffic Operations, Iowa DOT*; Jennifer Carter, *Sr. Manager of Government Solutions, HERE (representing USA and EU efforts)*; Sue Bai, *Principal Engineer of Automobile Technology Research, Honda R&D Americas*; Jun Shibata, *Senior Researcher, Japan Digital Road Map Association*; and Thomas Bamonte, *Program Manager for Automated Vehicles, North Central Texas Council of Governments*.

General Discussion

1. A dynamic map is not only a precise map database for AVs, but also an advanced information database for every vehicle and the vehicle environment. Information gathered may be used for many purposes including traffic management, road management, power-related facility management, and the prototyping of simulations.
2. Government bodies are asking how they can benefit from the data infrastructure.
 - There is a need to get information about events through the system to put out an alert, but the data needs to be granular. For example, while providing general information about an approaching construction zone is beneficial, additional information about lane closures, etc., would be more useful.
 - Data use cases may include, but are not limited to, crashes, road closures, weather conditions, potholes (through vehicle sensors), brake warnings, infrastructure diagnostics, parking availability, incident management, and enhanced maintenance decision-support systems.
 - For the data to improve safety, data needs to be fresh and monitored regularly. Protocols should be implemented for the sharing and reporting of basic data.
3. DOTs may benefit from a shift in perspective from that of a data owner to that of a data provider.
 - DOTs may be viewed as an authoritative source of quality data that may be trusted.
 - However, public agencies face additional liability-related challenges when it comes to sharing data. There exists a need to determine the extent to which data is

confidential versus public and which level of data (e.g., vehicle versus driver or passenger if automated system is in control) may be shared.

4. There are still a number of methods for collecting data. These methods vary across the country and have an impact on the ability of entities to share data.

- For data heterogeneity to be a realistic goal, will need to demonstrate that it can be done effectively and in a cost-conscious manner.

- Question remains of how to appeal to drivers to share their data. Key may be to appeal to their sense of good will.

- Event type may influence how data is handled and by whom. Most congestion is the result of nonrecurring events. That data needs to be passed along and routed to the entity that can best communicate the information. When it comes to managing the environment, unanticipated types of events (e.g., work zones, traffic signals, incidents, weather) are the most challenging. These are also the most challenging types of situations for drivers to traverse.

- OEMs will need to recognize that their role is changing to include that of a data supplier. OEMs are no longer the only key player, but are now one of many.

Moving forward, communication is key:

1. As communication is not perfect, entities need to continue to work together. By working together, data silos (e.g., infrastructure data, vehicle data) may be broken down.

2. Communication channels will need to be created between entities that hold different levels of data to determine what is most important and useful, what data can be shared, how that data may be shared, etc.

3. Communication will also help to build trust with the public, affirming that partners are working to make things better.

CLOSING DISCUSSION

The breakout concluded with a roundup of the session's major themes as determined through an interactive discussion among attendees. From the afternoon's discussion, two general categories of data emerged.

1. Safety and Performance Data. To be used to develop test cases, performance reporting, post-crash reconstructions, etc.

2. Infrastructure and Operations Data. Information related to road closures, weather events, incidents, emergency response, etc.

Challenges identified through the discussion include:

- Determining what data will be provided and what data will be asked for in return.
 - There is a need to determine what data is actually needed and the specific level of data needed to answer questions (e.g., braking data to determine icy roadways) as well as the fidelity and value of the data being shared. Without knowing what data are actually

needed, mass amounts of data could be collected, yet that data would not be useful because there is no clear plan of how the data will be used.

- There is also a need to distinguish between various types of data: cooperative data (work zone, incident, etc.) versus competitive data (user experience data, etc.).
- Determining who should take the lead—is it the private sector’s role or the public sector’s role to provide data or both.
 - In order to stimulate data sharing efforts, it is likely that activation energy will need to be expended to obtain initial buy-in to the data-sharing activities. Once buy-in to data sharing efforts is obtained from a couple of key players, additional buy-in will come more quickly.

Several opportunities that may help to facilitate the sharing of data were also noted:

- The public’s expectations are changing (changing expectations of how data is used, liability, and privacy). Because of these changing expectations, the public may be more willing to share data related to their vehicles or travel activities; and
- The federal government is set to have a role in scaling/architecture development.

SUGGESTED ACTION ITEMS

Follow-up research activities that center on the need for guidance regarding the distribution of responsibilities associated with data-sharing efforts, the storage and maintenance of data, the standardization of data elements, and the types of data that should be requested or shared would be beneficial. Participants suggested that the results of future research efforts would ideally do the following:

- Provide guidance on the roles associated with the parties who should be responsible for taking the lead on data collection, maintenance of data collected, and the sharing of specific data elements. Additional guidance will be required to distinguish between competitive data elements (i.e., those data elements that provide an OEM with a competitive advantage) versus cooperative data elements (i.e., those elements that can improve overall transportation system safety and support safety assurance).
 - Provide guidance to agencies on how to inventory and format data and how to assess data integrity.
 - Provide guidance on the standardization of certain data elements, especially those associated with road closures, incidents, emergency vehicle presence, and weather conditions and weather events.
 - Provide a roadmap for the “ask” of agencies to the private sector. The roadmap should include the information that could benefit services, maintenance, and operations.

APPENDIX K

Breakout Session 11: Artificial Intelligence and Machine Learning for Automated Vehicles *Exploring Tools, Algorithms, and Emerging Issues*

ORGANIZERS

Sherif Ishak, *Louisiana State University*; and Shawn Kimmel, *Booz Allen Hamilton*

REPORTERS

Hao Liu, *PATH, Institute of Transportation Studies, University of California, Berkeley*; and Somaye Fakharian, *Florida International University*

SESSION FOCUS

Autonomous driving relies on in-vehicle computers that emulate the functions of a human brain in making informed decisions. Such systems 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 AVs functions, as well as highlighted emerging issues and challenges to overcome with such advanced computing tools. This breakout session featured six presentations. The speakers focused how their work was aligned with the main theme of the session. This was the first breakout session sponsored by the TRB Standing Committee on Artificial Intelligence and Advanced Computing Applications.

PowerPoints of all the presentations are available on the AUVSI website at <https://higherlogicdownload.s3.amazonaws.com/AUVSI/14c12c18-fde1-4c1d-8548-035ad166c766/UploadedImages/2017/PDFs/Proceedings/BOs/Bo11-0.pdf> and <https://higherlogicdownload.s3.amazonaws.com/AUVSI/14c12c18-fde1-4c1d-8548-035ad166c766/UploadedImages/2017/PDFs/Proceedings/BOs/Bo11-1.pdf>.

SESSION SUMMARY

The six presentations demonstrated the use of AI and ML tools in various AV applications. Each application is summarized in the following pages.

A REAL-TIME DATA-DRIVEN DECISION-SUPPORT TOOLKIT FOR THE INCENTIVIZATION AND GUIDANCE OF SHARED, ELECTRIFIED, AND AUTOMATED VEHICLES

Chenfeng Xiong, *University of Maryland*

- A mobile-based platform was developed at the National Transportation Center at University of Maryland to promote the use of SEAVs.
- Different types of incentives in the transportation systems have recently drawn increasing attention to form smart-mobility solutions. Instead of using presumed and fixed incentives, the research developed an integrated, personalized, and real-time traveler information and incentive technology to incentivize more energy efficient travel, such as the adoption of SEAVs.
 - Based on ML and AI approaches, a behaviorally sound and computationally efficient agent-based modeling system was developed to simulate the entire transportation system in real-time.
 - Research used ML tools to identify the travel behavior patterns of commuters in the greater Washington, D.C., region based on a variety of data sources and large datasets.
 - Research also developed a Bayesian network model to predict the traffic flow patterns in the next few hours.
 - The results were further used to determine the incentives that can be offered to individual travelers to encourage them to adopt SEAVs. Through the mobile-based platform, predictive, personalized, and prosocial travel guidance could be offered to users.

COORDINATED DECENTRALIZED OPTIMAL CONTROL FOR CONNECTED AND AUTOMATED VEHICLES

Andreas A. Malikopoulos, *University of Delaware*

- The study recognizes the necessity of connecting vehicles to the surrounding environment wherein massive amounts of data from vehicles and the infrastructure have become available.
 - While progress has been made, especially in the area of safety and how accidents potentially could be prevented, one particular question that still remains unanswered is “how much can we improve fuel consumption, if we assume that the vehicles are connected and can exchange information with each other and with infrastructure?”
 - The study identified how to use CAVs to improve efficiency of the arterial corridors using a decentralized control to optimize the operation of intersections along the corridor.
 - Vehicles trying to pass an intersection were assigned trajectories based on the sequence they entered the control zone. Once the trajectories of a vehicle were determined, the trajectory information was further adopted to optimize the powertrain control.
 - The project indicated that CAVs can provide faster response while improving road capacity by identifying appropriate target speeds. Using both the traffic operation level and vehicle dynamics-level optimization, the efficiency of the road network can be greatly improved.
 - A decentralized optimal control framework yields the optimal acceleration–deceleration at any time in the sense of minimizing fuel consumption for each vehicle.
 - The solution, when it exists, allows the vehicles to cross the intersections and merge onto roadways without the use of traffic lights, without creating congestion, and under the hard safety constraint of collision avoidance.

- The speaker also highlighted past research efforts focused on making vehicles
 1. Eco-friendly;
 2. Realize the optimum efficiency based on consumers' needs and preferences; and
 3. Learn how traffic information can positively impact the environment and improve efficiency.

HOW MACHINE LEARNING AND SWARM INTELLIGENCE IMPROVE EFFICIENCY OF CONNECTED AND AUTOMATED VEHICLES

Xuwei Qi, *University of California-Riverside*

- ML and swarm intelligence (SI) have been applied successfully to various types of engineering problems and are now becoming more popular to further improve the performance of CAVs.
 - The speaker presented an overview of the current status of ML in CVs and AVs, followed by an introduction of case studies on how ML and SI improve the energy efficiency of CAVs through prediction, classification, and optimization.
 - The following case studies were presented:
 - Case Study 1: Supervised learning for connected eco-driving;
 - Case Study 2: Unsupervised learning for road mapping;
 - Case Study 3: Reinforcement learning for energy management system; and
 - Case Study 4: SI for multivehicle learning system.

A CENTRALIZED AND DE-CENTRALIZED APPROACH FOR INCENTIVE ALLOCATION AS A PART OF SMART MOBILITY SOLUTIONS

Mehrdad Shahabi, *University of Michigan*

- The speaker described the detailed algorithms used in the mobile-based platform introduced in the previous presentation.
 - Research aimed at achieving energy saving optimization by using a traveler reward system that offered specific monetary incentives to various user groups was described.
 - The research examined if a Bayesian network-based model and the CNN and k -nearest neighbor network could achieve the desired computational efficiency, solution quality, and robustness.
 - The model was therefore applicable for the implementation in a large-scale network where millions of agents were considered.
 - The proposed decentralized framework is robust to communication failure of vehicles with the central sever, and removes the computational burdens on the central server.
 - Results show that, at low penetration, 10% penetration of the platform could lead to an 8.3% energy reduction.
 - This methodology is scalable, since adding additional vehicles also adds computational capability.
 - In addition, through capturing various transportation network uncertainties at the individual vehicle level, better margins of reliability for the operation platform are achieved.

- Finally, a prediction model using AI techniques is adopted to predict the incentive allocation decisions at a user's level.

SEEING TRAFFIC SIGNAL BULB COLORS IS NOT ENOUGH: PREDICTIVE DATA FOR CONNECTED AND AUTONOMOUS DRIVING

Thomas Bauer, *Traffic Technology Services, Inc., Beaverton*

- The speaker said that one CV technology, eco-approach and departure from signalized intersections, or a specific subapplication known as Green Light Optimal Speed Advisory (GLOSA), is particularly beneficial for alleviating commute anxiety and reducing vehicle emissions and gas consumption.
 - Autonomous driving vehicles use cameras and computer vision algorithms to recognize current signal bulb colors and decide stop or go. The signal's time-to-change information is still missing, not allowing the AV to anticipate braking–acceleration maneuvers.
 - The research recognizes the need for AVs to predict signal phases before entering a fully actuated intersection.
 - The prediction data are then formatted into the SAE J2735 standard and delivered to the vehicle's OEM backend, which then disseminates the data over cellular or satellite networks to the vehicle for either dashboard display or engine management.
 - Such prediction could be used to optimize the trajectories of the AV.
 - A regression tree approach was proposed to perform the prediction. If the AV approaches on red, the algorithm gives the remaining time to green, provides advisory speed, and suggests time of brakes and early engine start time. If the AV approaches on green, the system provides advisory speed.
 - The system can also be used for transit operations to determine the green light optimal speed, red light duration countdown, station boarding duration advisory, and departure time window advisory.
 - This system has been successfully pilot tested in cities in the United States, China, and Germany. It was rolled out recently as the world first commercial infrastructure to vehicle data service into a premium auto OEM production vehicle in Las Vegas.
 - The benefits are convincing and have been realized by several automakers' HMI designs, as well as tied to engine and powertrain management for ride comfort and energy savings. Safety benefits have also become evident, where GLOSA could prepare commuters or heavy-vehicle drivers for anticipatory maneuvers in place of sudden and unsafe stops.

NVIDIA DRIVE ARTIFICIAL INTELLIGENCE PLATFORM FOR AUTONOMOUS CARS

Tim Wong, *NVIDIA*

- The speaker introduced NVIDIA Drive PX2, an AV hardware platform that supports multiple cameras, many interfaces, and connectivity.
 - The hardware platform can be enhanced by NVIDIA Drive open platform—a development environment for using NVIDIA Drive PX2.

- The speaker also demonstrated the process NVIDIA uses to calibrate the sensors in an AV and a sample trip of their prototype AV.

SUGGESTED ACTION ITEMS

This session aimed to establish a connection between the emerging AV applications and the existing–evolving AI and ML tools. The intersection between both fields offers unique opportunities for researchers to overcome the many challenges facing the design and development components of AVs. Given the diversity of the audience in the AVS, this session generated interest from various groups and bridged the gap between the various disciplines involved. Building on the success of this first session, a breakout session for the 2018 AVS that brings AI and ML tools to the attention of the vehicle automation stakeholders is planned.

APPENDIX L

Breakout Session 12: **Testing Connected and Automated Vehicles** *Accelerating Innovation, Integration, Deployment, and Sharing Results*

ORGANIZERS

Shannon Barnes, *CSG Government Solutions*; Jennifer Carter, *HERE*; Andrea Gold, *University of Texas, Austin, Center for Transportation Research*; Mathieu Joerger, *University of Arizona Transportation Research Institute*; Cynthia Jones, *Ohio DOT*; James Li, *Oak Ridge National Research Laboratory*; Taylor Lochrane, *FHWA Office of Operations Research and Development*; Barry Pekilis, *Transport Canada*; Valerie Shuman, *Shuman Consulting Group, LLC*; and Junhua Wang, *Tongji University*

REPORTERS

Cynthia Jones, *Ohio DOT*; Mathieu Joerger, *University of Arizona Transportation Research Institute*; and Junhua Wang, *Tongji University*

SESSION FOCUS

This session explored opportunities and best practices regarding 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. DOT has cited the acceleration of learning and development expected from the community of practice within the Automated Vehicle Proving Ground Pilot Program.

The session included a CAV proving grounds showcase, a panel and discussion on roles and partnerships in CAV testing, a panel and workshop on next steps to collaboration, and a lightning round to wrap up.

CAV PROVING GROUNDS SHOWCASE

Andrea Gold, *University of Texas, Austin, Center for Transportation Research*, moderator

TEXAS AUTOMATED VEHICLE PROVING GROUND PARTNERSHIP: BRYAN, AUSTIN, AND SAN ANTONIO, TEXAS

Mike Brown, *Southwest Research Institute*

Brown reported that a multiagency technology task force in Texas led to the creation of a CAV leadership team. Their first project was a collaboration of industry, academia, government, and other partners to submit a single Automated Vehicle Proving Ground Pilot Program application. Academic partners include Texas A&M University/Texas A&M Transportation Institute, the University of Texas, and the Southwest Research Institute. There are nine CAV test bed branches in Texas these include proving grounds, urban and freight testing sites, and fenced areas to test GPS. There are also international border crossings.

The initial roles of test beds are to

- Foster cooperation with industry partners and vehicle manufacturers;
- Provide testing facilities; and
- Gather data.

Brown extended an invitation to come test in Texas, noting that Texas is open for business and is working to enable new technologies. He noted the numerous urban test site partners and the desire to test as much as possible to obtain a robust understanding of AVs.

SUNTRAX AND THE CENTRAL FLORIDA AUTOMATED VEHICLE PARTNERSHIP, ORLANDO, FLORIDA

Mike Shannon, *Florida's Turnpike Enterprise*

Shannon described the new test facility in Central Florida with diverse partners including NASA. He noted that it was the first controlled, open high-speed track facility with automatic tolling. The inside of the track includes an urban simulation zone. The outside of the track is scheduled for January 2019 opening.

Shannon noted that the partnership is discussing how to develop a corridor that will eventually test driver-assisted truck platooning on a 483-mi toll facility. He stressed the importance of learning from the other U.S. DOT AV Proving Grounds sites. He further noted that the Florida legislature requires a pilot.

IOWA AV PROVING GROUNDS, IOWA CITY, IOWA

Daniel V. McGehee, *National Advanced Driving Simulator Laboratories, The University of Iowa*

McGehee described the Iowa AV Proving Grounds, which represents a partnership among Iowa State University, the University of Iowa, the Iowa DOT and other groups. He noted that the Iowa National Advanced Driving simulator has a 15-year history, and an \$80 million investment. The simulator is being used to evaluate how drivers respond to different levels of automation, including fully automated vehicles. The virtual testing ground, called "Springfield," is approximately 285 mi by 285 mi. He noted that I-35 and I-80 have heavy volumes of trucks. One focus of the proving ground is on improving safety, broadening mobility for the elderly, and

increasing freight. Examples of rural risks that have been identified include stopped school buses or slow moving tractor traffic, recognizing the needs farm-to-market economy. He also noted that there is a major focus on HD mapping.

GOMENTUM STATION CONTRA COSTA TRANSPORTATION AUTHORITY, CONCORD, CALIFORNIA

Randy Iwasaki, *Contra Costa Transportation Authority*

Iwasaki described GoMentum Station. He noted that the GoMentum Station includes approximately 5,000 acres available for testing. He noted the advantage of having a site with existing transportation infrastructure, including tunnels and bridges. Future plans call for building a roundabout and a model city with housing. He described existing partners and ongoing outreach efforts for additional public, agency, business, and academic partners. International partners are also being pursued. He noted they are also identifying industries that will be disrupted by driverless cars including insurance, auto repairs, professional drivers, hotels, airlines, auto parts, TNCs, public transit, and parking lots. Iwasaki noted the interest in sharing experiences with other test beds.

UK CENTRE FOR CONNECTED AND AUTONOMOUS VEHICLES, UNITED KINGDOM: LONDON (GREENWICH), COVENTRY

Milton Keynes, *Bristol, Oxford, Cranfield Interurban Roads*, and Iain Forbes, *CCAV*

Forbes discussed the idea of a self-sustaining ecosystem. He described the robust private and public test facilities in the U.K. Examples of these test facilities cited by Forbes included the Millbrook Vehicle Proving Grounds, Nissan's European Technical Center, Cranfield University's test sites, and the Transport System Catapult. Other facilities in London included the U.K. Smart Mobility Lab in Greenwich, the GATEway trial (the connector corridor from London to Dover), and the Volvo arterial road project. He noted that there are also facilities around Oxford, Bristol, and the Midlands.

Forbes noted that targeted government investment can help solidify and integrate these capabilities. He described the competitive call for collaborative programs being used. He also stressed the importance of partnerships with numerous public and private groups.

K-CITY, KOREA

Taehyung Kim, *Korea Transportation Institute*

Kim described the K-City Test Bed in Korea. The goal of the testing facility is to ensure the safety of AVs and other road users. He noted that K-City includes approximately 320,000 m and includes a motorway, an urban area, a community with parking, and a rural road. Kim said that many evaluation scenarios are being examined. He noted that K-City has more than 15 partners and that six AVs will be tested in the initial phase.

SUMMARY

- Encourage partnerships between agencies and test facilities so funds are not wasted on construction.
- Use what you have and collaborate on other elements.
- Each facility and program has specialties, every program is different, and it is most effective to collaborate and plan complementary testing.

ROLES AND PARTNERSHIPS PANEL

Taylor Lochrane, *FHWA Office of Operations Research and Development Moderator*

ITS Japan

Hajime Amano

Amano described testing facilities and partnerships in Japan. He discussed the development of the dynamic map platform, which involved many collaborators, including the Japanese automobile manufacturers association. He noted that the Traffic Signal Prediction Systems is in place at numerous intersections. Test sites will be available at no cost, including expressway, urban roads, and other environments. The National Police Agency has issued rules associated with testing.

Europe ITS ERTICO

Maxime Flament, *ERTICO*

Flament provided an update of European activities (see connectedautomateddriving.eu for more information). He reviewed the Declaration of Amsterdam, which was discussed extensively at the 2016 AVS. He noted that the Declaration addressed EU cooperation in connected automated driving. He also noted that the EU Transport Ministers meet every 6 months to report on progress.

In Germany there is a digital motorway test bed on A9 in Bavaria near Karlsruhe. The facility includes message signs, roadside infrastructure—sensors, Internet, HD maps, road markings, and interactions with traffic management centers. There is also a Volkswagen city in Lower Saxony.

The “France nouvelle” collaboration is focusing on experiments, ecosystems, and technologies. Further, there is French and German cooperation in the Alsace region.

Drive Sweden includes numerous development, testing, and deployment projects. The Drive Me project involves 100 families using self-driving cars on certified public roads in Gothenburg. Pilots of platooning multibrand trucks is also underway. The ASTAZERO test facility includes numerous roadway configurations and components.

Transportation Research Center, Inc.

Brett Roubinek, *Transportation Research Center, Inc.*

Roubinek discussed the Transportation Research Center (TRC) in the Columbus, Ohio, region. TRC was developed in the 1970s by Honda. He noted that they are currently working with the Ohio State University to expand TRC's capabilities to include a high-speed intersection, an urban network, a vehicle dynamics area, and a control center. Additional improvements will include an indoor winter weather condition facilities and a 3-mi loop to recreate highway settings. He noted that there are also coordinated activities underway in the corridor with a partnership among the Columbus Smart City project, the cities of Dublin and Marysville, and the TRC. For example, fiber has been laid throughout the corridor to provide connectivity.

NEXT STEPS TO COLLABORATION PANEL

Valerie Shuman, *Shuman Consulting Group, LLC, moderator*

Panelists

Carla Bailo, *The Ohio State University*; Sondra Rosenberg, *Nevada DOT*; and Ed Bradley, *Toyota Motor North America*

Panelists discussed research needs, sharing research results, and additional test beds. Common research needs across the global test beds identified by panelists included public acceptance, human behavior, and planning. Obtaining a better idea of public acceptability was suggested as important by panelists.

Other research needs:

- Combinations and permutations of AI and AVs.
- Communication between machine and person-gesture, movement, understanding vehicles.
- Data and data management.

Panelists discussed sharing test results: what makes sense or does not make sense.

- Academics want to publish everything. Basic research can be published; intellectual property allows testing for private firms.
- Test data for near-crash situations and scenarios.
- DOTs want data, and are both data-rich and information-poor. DOTs need to define what data is needed to operate the system. Near-crash and failure information is important.

Panelists discussed if 10 other test beds were available and what three categories of results would be beneficial.

- Translating information to public road behavior.
- Mapping of closed to open so the testing is closest to reality, and minimize risk.
- Worst cases: geography, weather, and driver behavior.

WORKSHOP EXERCISE

Instructions

Working in small groups, the breakout group participants were provided with the opportunity to develop a global test bed collaboration plan. The participants were asked to focus this plan on areas where collaboration is most important. They were asked to prioritize the following items:

- 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, and other related items.
- Top five shared test results. What tests should we be carrying out at multiple facilities to get a larger and more diverse shared data pool around specific issues? For example, interoperability testing and other elements.
- Top five best practice areas. What areas will most benefit from sharing across test beds? For example, cybersecurity best practices and consumer data management handling.

Identified Priorities

Each group reported their top priority in three areas and there was a brief discussion to identify the shared priorities. A further review of the detailed results from each table revealed the following common topics. Specific items for each topic are included to illustrate the range of issues identified. The descriptions are presented based on the participant summary sheets to preserve language and concepts.

Research Goals

- 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 issues—transfer within mode, HMI usability.
 - Assess the impact from and to national regulations, including the effect of out-of-the-loop driver activities.
 - Human factors engineering.
- Performance:
 - Performance comparison to human drivers with diverse skill levels. Consider competency levels such as new drivers, drivers with commercial driver’s licenses and other professionals, and elderly drivers.
 - Common performance across sites and systems.
 - Performance standards.
 - Technology readiness level equivalent for AVs, including problem specification.
 - Competency test for vehicles.
- 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 and society awareness of short-term benefits and demonstrable added value.
- Specific technology and application areas:
 - Focus on core technology areas, including machine vision, connectivity, and mapping.
 - Identify what 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

- Common methodologies and standards
 - Safety protocols, including stopping distances.
 - Data collection procedures.
 - Test procedures and methodologies: share with others conducting 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 versus black-box testing.
 - Starting conditions; likelihood of someone altering or affecting the test.
 - Develop some level of classification of what should be shared and how it should be shared.
 - Standardize processes, data, and KPIs that allow comparison between tests, i.e., key variables.
 - Global data sharing standards to address privacy and cybersecurity issues.
- Failure data:
 - Shared failures, including sensor discrepancies when sensors do not detect the same thing consistently.
 - Near-crash and crash data: what led to these incidents?
 - AV system disengagement reports and requests for re-engagement.
 - Test and crash fatalities.
- Weather and environmental data:
 - Simulation of extreme weather conditions.
 - Effects of differing site conditions.
 - Geographic variations.
 - Sensor accuracy and capability across environments.

Best Practice Areas

The small groups provided a very diverse set of answers to this question. The two most common answers are noted below, but a range of specific technical and institutional topics were additionally identified by participants.

- 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.
- Interoperability: Communication interoperability.

SUGGESTED ACTION ITEMS

- Participants supported continuing conversations about effective AV testing, and sharing the Draft Global Test Bed Collaboration Plan. Participants noted that it is a critical, global concern that cannot be solved by the U.S. government alone or any one party.
- Participants suggested focusing testing on safety to create a “Moonshot” with collaboration.
- Participants identified the need to define roles to engage public, private, and academic partners.
- Participants stressed the need to take advantage of opportunities for sharing through integrated data exchanges, especially with near-crash and crash data.

APPENDIX M

Breakout Session 13: Challenges and Opportunities for the Intersection of Vulnerable Road Users and AVs

ORGANIZERS

Justin M. Owens, *VTTI*; and Laura Sandt, *University of North Carolina Highway Safety Research Center*

REPORTER

Jill F. Cooper, *University of California Berkeley Safe Transportation Research and Education Center (SafeTREC)*

SESSION FOCUS

This session focused on discussing ways in which AV systems could potentially have an impact on the safety and mobility of VRUs, both beneficially or potentially problematically, and exploring technology, infrastructure, and policy tools that can be utilized or pursued.

The session consisted of two panels. The first panel focused on understanding pedestrian and bicycle injury data, including safety concerns faced by individuals with disabilities. The second panel focused on AV technology and environmental and planning issues related to pedestrians and bicyclists.

PowerPoints of most of the presentations are available on the AUVSI website at <http://www.automatedvehiclessymposium.org/program/proceedings>

PANEL 1: VULNERABLE ROAD USER SAFETY NEEDS AND CONCERNS

Laura Sandt, *UNC Highway Safety Research Center, moderator*

Welcome and Session Overview

Laura Sandt, *UNC Highway Safety Research Center*

Sandt noted that AVs present the potential of greater road safety due to a reduction in human error, but suggested that it is important to consider the impact of vehicle automation on VRUs, including pedestrians and bicyclists. She further noted that issues concerning VRUs must be addressed for AV technology to expand substantially.

Sandt highlighted the following concerns for discussion.

- Detection of VRUs by AV sensors, especially during darkness.

- Lack of data, resources, and studies concerning pedestrians and bicycles and AV; therefore, VRU issues are not well documented.

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

Justin F. Morgan, *Forensic Engineering Technologies*

Morgan discussed that one valuable method of determining the conflicts that could possibly emerge from the interaction of AVs and VRUs is to study current conflicts between vehicles and VRUs, using forensic evaluation techniques to reconstruct actual crashes.

Morgan noted that current collision-prevention methods includes speed reduction, roadway treatments and countermeasures, and passive and active safety systems. He noted that even with these methods, crashes still occur, and often have multiple contributing and causal factors. He said that one major factor is limited visibility. Automation could potentially support pedestrian and bicycle safety by improving the detection of VRUs using onboard sensors or external communication protocols such as DSRC. He noted that these types of systems could not only help in cases of human error, but also in cases where the built environment does not always support effective detection of VRUs by drivers or when something unexpected happens. In addition, even in cases where collisions cannot be prevented, severity may be mitigated to some extent if a vehicle is able to detect a VRU and slow more quickly than a human driver could.

Key Human Factors Challenges and Opportunities within AV/VRU Interactions

Justin M. Owens, *VTTI*

Owens noted that the current interaction between drivers and VRUs is fairly well understood and relies to some degree on social interactions. Many public safety campaigns focus on improving eye contact and gestural communication between pedestrians and drivers. As fleets transition to automation, he said that vehicle–VRU interactions may shift from bidirectional human communication to unidirectional HMIs. He suggested that it was important to consider that roadways will host a mixed fleet of vehicle automation for the foreseeable future and that roadways will not transition overnight to full automation.

Owens reported that AVs present a variety of potential benefits to VRU safety, including the preclusion of distracted, fatigued, or angry drivers as well as better reaction time. Further, AVs could potentially improve efficiency in pedestrian–traffic flow, and may provide opportunities for enhanced safety and mobility for pedestrians with disabilities. He suggested that there is a need for increased human factors research with growing automation, and to address questions about interactions between humans and AV. Owens and Laura Sandt are working on a paper on HAVs that deals with both technical and social issues. The following key questions concerning interactions between AVs and VRUs are being addressed in the paper.

- How can AVs improve upon current VRU safety strategies (e.g., pedestrians' making eye contact with drivers) and public safety messaging?
- How will AVs improve detection of pedestrians in the roadway, especially at night, or with occlusions?
 - For SAE Levels 2 and 3: when should the vehicle demand operator takeover, and will this vary in areas with high pedestrian traffic?

- Discussion of V2X considerations in detection of pedestrians and bicyclists.
- How to guide development AV algorithms to respond cultural and geographical differences in pedestrian and bicycle behavior concerning right of way, jaywalking, passing bicycles, and social customs?
- How should AV systems determine when and how to pass a bicyclist?

Owens noted that there is need for ongoing human factors work, both in the real world and using advanced simulation. He described a VR driving simulator that could enable the testing of AV–VRU communication systems without the risk that research on a real roadway entails.

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

Sudharson Sundararajan, *Booz Allen Hamilton*

Sundararajan noted that there are four primary types of disabilities that should be considered in the development of AVs: vision, mobility, hearing, and cognitive impairments. The potential target population of people with disabilities includes veterans with disabilities and older adults. He reported that the need to address safety among this group is increasing worldwide each year. Additionally, individuals using medications and those with mental health issues affect roadway safety. He suggested that partnering broadly with stakeholders, including occupational therapists was critical. He highlighted the following questions which need to be addressed.

- How will AVs accommodate people with disabilities who need more time to cross the street, are not able to hear horns, and are more or less aggressive at intersections?
- How will AVs deal with issues of pedestrians challenging AVs to stop.
- What are the specific differences between pedestrians with various disabilities and able-bodied pedestrians from a functional standpoint?

PANEL 2: TECHNOLOGY, INFRASTRUCTURE, AND POLICY CONSIDERATIONS

Michael Clamann, *Duke University Humans and Autonomy Lab, moderator*

Clamann discussed that while NHTSA has developed a policy addressing AVs, it includes only minimal consideration of pedestrians. He suggested that pedestrian and bicycle researchers, practitioners and advocates should be present in national and state planning efforts. He noted that currently, there is much state-level legislation pending concerning AVs, but that the degree to which this legislation addresses VRUs is not known.

AutonoVi: A Simulation Framework for Autonomous Driving

Dinesh Manocha, *University of North Carolina, Computer Sciences Department*

Manocha discussed AutonoVi-Sim, which is a comprehensive simulation framework for evaluating and optimizing essential autonomous driving technologies. He noted that it includes algorithms for navigating complex traffic behavior, including complex road environments, pedestrians and vehicles, and bicycle and vehicle interactions. It is modular to allow revision of algorithms, roadway features, and ITS, as well as new scenarios.

Manocha reported that project researchers are working to simulate challenges associated with road conditions, weather, lighting, driving behaviors, social and cultural factors, accidents, and dynamic incidents.

Manocha noted that in developing the simulator, researchers studied how decisions are made about acceleration, deceleration, lane changes, and other factors. Researchers also modeled and simulated situations with pedestrian and bicycles, including jaywalking and speed. Testing perception and behavior learning from real-world data are planned. He noted that the overall goal is to develop a general-purpose autonomous driving simulator for research and industrial use.

Bystander Interaction with Autonomous Vehicles and Robots

Aaron Steinfeld, *CMU*

Steinfeld discussed several studies that explored issues of trust and behavior between road users and robots, with the goal of better understanding how to improve acceptance and safe interactions between road users and AVs. He noted that it is important to determine what actions are appropriate, how to avoid violating user expectations, how to avoid seeming “rude,” and how to engender trust that a vehicle will not drive into a pedestrian crossing a crosswalk. He commented that this last point is particularly interesting, as in some cases the knowledge that human drivers may not be trustworthy (e.g., may go when it is “their turn”) is important to stable traffic flow.

Steinfeld described research investigating the acceptability of a vehicle that can automatically park, which was intended to provide older adults with better door-to-door service, as well as a recent project that conducted survey research on the opinions of pedestrians about automated rideshare vehicles in an urban environment.

Urban Form and Automated Flows

Tanvi Maheshwari, *Future Cities Laboratory, Singapore*

This presentation addressed how an increasingly automated vehicle fleet might affect urban form. Maheshwari discussed how AV deployment can enhance the safety and overall experience of walking and bicycling, rather than limit it. The role segregation of transportation modalities may play was also described. Maheshwari suggested that while these general questions have been discussed since the advent of the automobile, they are newly relevant given the impending shift in the vehicle fleet. There is a need to develop measures to show indicators of urban design that promote walking–biking and explore how to retrofit the current urban form to enhance the network for VRUs. The presentation also explored designing for taxi and ridesharing models, government and regulated fleet models, personal ownership models, and restricted use models.

SUGGESTED ACTION ITEMS

AV Design–Human Factors Research

- Participants suggested using current crash scenarios to predict conflict types and data needs for AV–VRU interactions.
- Participants identified that research was needed exploring methods of AV detection of pedestrians and bicycles, and determining ways to improve upon the current state-of-the-art.

The research could examine how V2X communications can assist in detection, and the potential benefits and limitations of this technology from behavioral and technical standpoints.

- Participants noted that research should be conducted into the technical, human factors, and cultural issues surrounding communication of intent among AVs and VRUs, including how is right-of-way determined and communicated.
- Exploring designs that can respond to cultural and geographical differences in pedestrian and bicycle behavior concerning right of way and social customs was another research topic identified by participants.
- Participants suggested that research should be conducted to optimize the passing behavior, both decision and distance, of AVs around VRUs, particularly bicyclists.
- Another research topic identified by participants was exploring the use of simulators to test interactions between AVs and a variety of VRUs, including older adults, children, and people with a range of disabilities. It could also explore issues associated with AVs passing bicyclists.

Communications

- Participants discussed the need for research to develop and test messages needed to educate VRUs about AV technology, including best practices to communicate the benefits of AV to a broad audience.

Legal and Ethical Questions

- Participants identified the need for research addressing legal and ethical issues including when AVs could break the law, liability in the case of crash, and the legal responsibility in crashes involving non-AV vehicles, AVs, and VRUs.

Data

- Participants identified a number of research needs related to data. Research topics included exploring driver assistance technologies that currently work well, exploring standardization of data, and building a database consisting of AVs' and VRUs' interactions, crashes, and lessons learned.

APPENDIX N

Breakout Session 14: Enhancing the Validity of Traffic Flow Models with Emerging Data

ORGANIZERS

Meng Wang, *Delft University of Technology, Chair*; Xiaopeng (Shaw) Li, *University of South Florida, Co-Chair*; Samer Hamdar, *George Washington University, Co-Chair*; Haizhong Wang, *Oregon State University*; Soyoung Ahn, *University of Wisconsin – Madison*; Mark Brackstone, *TSS*; Danjue Chen, *University of Massachusetts Lowell*; Steven Mattingly, *University of Texas Arlington*; Alexander Skabardonis, *University of California, Berkeley*; and Michael Levin, *University of Minnesota*

REPORTER

Michael Levin, *University of Minnesota*

SESSION FOCUS

This breakout session provided an opportunity to bring together the TRB cyberphysical, communications, vehicle, and traffic flow communities to better understand the fundamental characteristics of traffic flow with varying levels of automation and identify the research needs for developing models to assess real-world mobility and to assess environmental sustainability implications of CAVs. The breakout session focused on the 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 design. Special attention was given to insights into behavioral differences in terms of lane-changing (lane choice and lane change execution) and car-following (following gap, reaction time, and acceleration distribution) maneuvers, and validation of existing and new CAV traffic flow models according to empirical data from CAV field tests.

PowerPoints of most of the presentations are available on the AUVSI website at <http://www.automatedvehiclessymposium.org/avs2017/program/proceedings>. Session summaries are as follows.

RELEVANCE AND CHALLENGES

Meng Wang, *Delft University of Technology*

- Wang noted that AVs will cause 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), and their effects on traffic will depend on parameter choices.

- Wang outlined several major open questions for traffic flow researchers.
- Are models good enough in describing driving behavior and how it reacts to technological advances? Do they differentiate the decision-making process for different levels of automation? Do we understand the differences?
 - Available and usable data are needed to answer these questions. There is also a need to design data collection for traffic-flow calibration.

USING AV PILOTS TO INFLUENCE PUBLIC OPINION

Rita Excell, *Australia and New Zealand Driverless Vehicle Initiative*

Excell noted that governments (such as Australia) are providing opportunities for AV pilot programs. How can they be used to affect public opinion and collect data? For example, a demonstration in Adelaide on public roads reached 15 million viewers through Australian Driverless Vehicle Initiative media coverage.

- Excell noted that a public perception survey found widespread acceptance, although levels of comfort and concern varied based on the technology and use. Overall, 46% responded that they believe AVs will be safer, but 83% would like to drive manually from time to time. Comfort levels varied for different driving tasks, such as lane changing and route choice. Overall, 38% responded that they were willing to pay more for automation.
 - Data collection was qualitative and included how CAVs respond to existing infrastructure, markings, and signage.
 - Excell suggested that testbeds should involve public roads, and that cities are willing to open their roads for testing. Investments or focus in one corridor could generate more usable data, however.

CONTROL OF TRAFFIC WITH A SMALL NUMBER OF AVS

Daniel Work, *University of Illinois at Urbana Champaign*

- Work noted the transition 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 the traffic stream). Mobile sensing is already available through cell phones. The next step is mobile control.
 - Work suggested that enough data is available to analyze the impacts of disasters on cities. For instance, there were clear reductions in traffic congestion near Hurricane Sandy. As the recovery process began and services reopened, gridlock was observed.
 - Work described the ring experiments (20 cars driving around a ring), which showed that a small number of AVs can improve traffic. A small variation in human driving behavior can cause congestion. Instabilities result from accelerations and braking, and propagate to trailing vehicles, increasing in magnitude as they propagate.
 - Work said that predicting instabilities requires a second-order flow model. For AVs, a smoothing term was added to relax toward the equilibrium velocity (with equilibrium measured by human drivers).

- Work described tests that were conducted in Arizona with one AV and 19 human-driven vehicles. The AV speed control reduced braking events by 98.6%, the standard deviation of speed by 80.8%, and fuel consumption by 42.5%.
- Work noted that finding the optimal parameters is still open; a parameter sweep was used for the results. There is some disconnect from the mathematics and simulations to the actual controllers due to the need for a safe gap to avoid real collisions.
- Work said that more than 5% of the fleet being tested in a highway setting needs to be AVs.

RECENT FINDINGS FROM MICROSIMULATION OF TRAFFIC IMPACTS OF COOPERATIVE LONGITUDINAL CONTROL SYSTEMS

Steven Shladover, *PATH Program, University of California, Berkeley*

- Shladover noted that many microsimulation models do not reflect actual adaptive cruise control (ACC) and CACC behavior. Drivers have several modes of manual driving, including combinations of lane changing and car following behaviors.
- Using four identical Nissan AVs, Shladover developed microsimulation models of ACC and CACC, and calibrated the models driving the vehicles on Sacramento SR-99 freeway. ACC and CACC modes were added to manual driving modes.
- The model results showed that ACC caused worse shockwaves than manual driving: 5 s to propagate through four vehicles. The reason is that human drivers look more than one vehicle ahead. With CACC, cars accelerate and decelerate together, which reduces the magnitude of oscillations when they propagate backwards. He noted that communications are important for AV efficiency.
- A variety of experiments were performed on a highway network segment, with variables of on-ramp and off-ramp volume, CACC minimum gap, and AV market penetration. Overall, capacity increased with CACC market penetration. On-ramp volume decreased downstream throughput. Off-ramp volume also reduced throughput with managed lanes due to vehicles weaving from managed lanes to the exit ramps.

Shladover said that CACC reduced discretionary lane changing because it is often preferable to remain in a CACC string than change to a slightly faster lane. He noted that the effects of ACC and CACC are subtle and require careful calibration of microsimulation with real testing.

CONNECTED AND AUTOMATED VEHICULAR FLOWS: MODELING FRAMEWORK AND DATA AVAILABILITY

Jiaqi Ma, *Leidos, Inc.*

- Ma described an FHWA project at the Saxton Lab, which developed an analysis, modeling, and simulation (AMS) framework to analyze demand-side and supply-side impacts of AVs.
- Ma noted that I2V specified an eco-drive mode, optimizing fuel consumption by giving speed and powertrain commands to CAVs. Data collection efforts involved five vehicles

with cellular/LTE, corrected GPS, and DSRC. Several sensors were used to estimate speeds, fuel consumption, and braking.

- Ma described a field experiment that was conducted on I-66. The goal was to create a rolling block of three AVs to smooth following traffic. A lead probe vehicle experienced much greater speed oscillations than probe vehicles behind the AV block.
- Other V2V controls developed include a protocol for vehicles to merge into CACC strings.
- Ma noted that eco-approach and departure at signalized intersections could reduce fuel consumption by slowing down or accelerating vehicles to avoid complete stops.

Overall, Ma said that more data is needed, but limited numbers of AVs are available. Hardware-in-the-loop testing could be used to combine real data collection with simulation. CAVs will need new types of tools and controls, and data is needed to calibrate key model components.

HIGHLIGHTS FROM PANEL DISCUSSION

- Panelists and participants discussed that 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 it risks reverse engineering proprietary software through observation of powertrain commands.
- Panelists discussed that ACC minimum safe gaps for reverting to human control often seem quite low: for instance 0.6-s headways on freeways. However, test subjects were generally comfortable with such gaps, although longer time headways would be needed on roads with lower speeds.
- Participants discussed that estimating the effects of AVs during the transitional period requires more accurate modeling of human driving. Models often make errors that cancel each other out through calibration. Some of these errors will be removed with partial automation. The study described by Shladover used 75% of the total resources to calibrate the human driving model.
- Panelists noted that 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. Additionally, current CACC systems often use constant time gap headways, whereas platooning systems use constant clearance distances.
- Panelists and participants discussed that models should include vehicle dynamics and receipt and response to communications. It was suggested that 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 underlying causes is sufficient.
- Participants discussed that existing, or currently available AV technologies, should be used for data collection. Future opportunities may offer better data collection, but technologies supported by companies now avoid development costs. Additionally, standard fixed sensors and controls are better for some types of data collection and traffic control than new technologies.

- Some participants noted that other types of AV applications, such as freight, are more economically driven. AVs are being considered with railroads because of the reduction in cost. Part of the large infrastructure costs for freight transport could be directed toward modeling the traffic flow and economic impacts.

- Participants suggested that research models possibly will not to be implemented directly by the automotive industry, which has proprietary software. However, research can illustrate errors or issues for companies, such as the benefits of one type of longitudinal controller. It was also suggested that 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 not accurate when actually used on the road.

- Participants discussed that the development of common testbeds and data is an issue. Sharing data with other researchers requires considerable expense for documentation and support. Data confidentiality becomes an issue as well. Driver behavior, such as car following and lane changing, also varies by country.

SUGGESTED ACTION ITEMS

- Participants suggested that developing partnerships with companies developing AVs should be pursued to test and collect data.

- Participants suggested it was important 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 reducing traffic congestion.

- Participants supported allocating funding in AV tests for documenting and sharing data.

- Participants suggested that creating a forum for sharing main lessons and ideas with AV manufacturers without getting lost in the details would be beneficial.

APPENDIX O

Breakout Session 15: CAV Scenarios for High-Speed Controlled-Access Facilities

ORGANIZERS

Christopher Poe, *Texas A&M Transportation Institute, Co-Lead*; Steve Kuciemba, *WSP, Co-Lead*; James Colyar, *Federal Highway Administration*; Taylor Lochrane, *Federal Highway Administration*; Greg Krueger, *HNTB*; Nick Wood, *Texas A&M Transportation Institute*; Patrick Vu, *VTA*; Angela Jacobs, *Federal Highway Administration*; Alex Skabardonis, *University of California Berkeley*; Tim Gates, *Michigan State University*; and Jon Obenberger, *Federal Highway Administration*

REPORTERS

Christopher Poe, *Texas A&M Transportation Institute*; and Steve Kuciemba, *WSP*

SESSION FOCUS

This session focused on scenario planning for CAVs on controlled access facilities such as freeways, managed lanes, and tollways. Through a series of presentations and small group discussions, session participants focused on critical infrastructure components, near-term issues, and long-term concerns for four specific scenarios with operational and real-world implementation perspectives at the forefront. This session was developed jointly by members from the TRB Freeway Operations, ITS, Managed Lanes, Highway Capacity and Quality of Service, and Traffic Control Device committees.

SESSION SUMMARY

Controlled access facilities, such as freeways, managed lanes, and tollways, are high functioning roadway infrastructure. Participants discussed that these facilities may offer early deployment of CAV technologies and projects. To establish the perspective from different industry sectors, the breakout session began with a panel of speakers representing an infrastructure owner operator (Greg Larson, *Caltrans*), an infrastructure vendor (Sinan Yordem, *3M*), the automotive industry (Roger Berg, *DENSO*), and a public transit agency (Casey Emoto, *Santa Clara Valley Transportation Authority*).

The TRB Committees on Freeway Operations, Managed Lanes, ITS, Highway Capacity and Quality of Service, and Traffic Control Devices sponsored this session to examine four specific use cases: temporary traffic control events (such as a work zone or incident); truck automation and platooning; CAVs in mixed traffic on freeways; and transit and shared mobility

using CAVs. Representatives from the committees presented an overview of the different scenarios.

SCENARIO OVERVIEWS

- Greg Krueger, *HNTB*. Temporary traffic control event (work zone or incident scenario).
- Mike Lukuc, *TTI*. Truck automation and truck platooning on controlled access facility.
- Alex Skabardonis, *UC Berkeley*. CAVs allowed on freeways in mixed traffic.
- Nick Wood, *TTI*. Transit and shared mobility using CAVs on dedicated managed lanes.

The session organizers facilitated a discussion with the session participants examining near-term issues (defined as 1 to 5 years) and long-term issues (defined as 5 to 10 years) for each of the scenarios.

The following general observations were recorded from the entire session discussion across all the scenarios.

- CAVs offer improvement in safety, throughput, and congestion.
- There is a need to consider the entire transportation network.
- Many opportunities exist in data sharing, but there are also challenges.
- There is a need for simulation tools to assess impacts and operations.
- More information is needed on when and where platoons should operate (truck, car, bus, and mixed).
- Work zone design may need to change based on CAVs.
- More research is needed on how to integrate CAVs into the managed lane operation spectrum.

The use case descriptions, near-term issues, and long-term issues discussed are highlighted next for the four scenarios.

Use Cases

CAVs for Transit and Shared Mobility	
Use Case Description	<p>Some transit agencies and TNCs are considering using CAVs on dedicated managed lanes to improve overall serviceability. The promise of CAVs offers a scenario where vehicle headways could be reduced, increasing the total vehicle and person throughput within the lane. As a long-term scenario, transit and other ridesharing services could offer driverless vehicles that could lower operating costs by not requiring drivers. Transit agencies could develop a broad-based program that allows many rideshare services to use the dedicated lane and receive rewards and discounts. CVs might lessen the need for on-road signage by transmitting the cost of tolls and other information to drivers using in-vehicle technology. Additionally, CAVs could lead to an enhanced ability for checking vehicle occupancy, thereby reducing the need for onroad enforcement personnel.</p>
Near-Term Issues	<ul style="list-style-type: none"> • Infrastructure needs depend on vehicle design. • How do you accomplish first mile and last-mile operations? • Need to consider toll versus free lanes. • Need to consider occupancy detection and lane use signs. • Needs in a dedicated lane may include active traffic management and clearance detection. <ul style="list-style-type: none"> • Consider a system of freeway and arterial management lanes with transit signal priority. • Consider vehicles as probes to help TMC operators make decisions on opening managed lanes to all traffic.
Long-Term Issues	<ul style="list-style-type: none"> • Consider the business model for person throughput - can it be sustained just on a highway? • Shared van versus full bus, vehicle design. • Consider dedicated lanes for transit or transit-only access. • Examine integrating employee shuttles and express buses. • Ridership data, private app provider (Chariot). • Consider that buses have different merge impacts and that different headways impact lane design. <ul style="list-style-type: none"> • Consider wireless electric charging for EVs. • Develop rural and urban scenarios. • In a full AV scenario will dedicated lanes be needed?

Continued on next page.

Use Cases (continued)

Truck Platooning and Automation	
Use Case Description	<p>Level 2 truck platooning extends radar and V2V, communications-based, CACC using precise automated lateral and or longitudinal vehicle control to maintain a tight formation of vehicles with short following distances. A manually driven truck leads a platoon, allowing the driver(s) of the following truck(s) to disengage from driving tasks and monitor system performance. Level 1 truck platooning has demonstrated the potential for significant fuel savings, enhanced mobility and associated emissions reductions from platooning vehicles. In this application, the driver(s) of the platooning vehicle(s) behind the lead truck are still responsible for steering. In Level 2 and Level 3 truck platooning, these drivers also can disengage in the steering task. Level 2–3 automation may increase these benefits while reducing driver workload and increasing safety. Platooning systems are designed for use at highway speeds, although they can function in stop-and-go traffic. Research and industry plans suggest that platooning of Class 8 commercial vehicles will likely be contained to rural stretches of Interstate, or other controlled access facilities with a median and no cross-over lanes for use by normal traffic, in the near term. This approach will allow for the realization of benefit and a safe introduction of the technology.</p>
Near-Term Issues	<ul style="list-style-type: none"> • Identify roads that are appropriate for truck platooning, with consideration that trucks could be different than car platoon lane use policies. • Examine the need for disengagement zones for trucks. • Consider road conditions, restrictions, truck weight, as well as the positioning of loads. • Examining tolling, weigh-in-motion, overheight vehicle issues. • Examine enforcement awareness of platoons by motorists. • Consider the size of platoons versus the location of platoons: near term lower levels and smaller trains. • Examine the potential impacts on mixed traffic. • Examine platoon configuration with long combination vehicles.
Long-Term Issues	<ul style="list-style-type: none"> • Consider the size of platoons and configuration (i.e., two-truck platoons, three-truck platoons) versus road configuration (i.e., four-lane freeway, six-lane freeway). • Examine the issues identified in the Southern California Association of Governments study in the Los Angeles area and an inland empire truck AV lane. • Examine electronic enforcement application with platooning. • Consider interfleet and intrafleet operations, including issues associated with data exchange, platooning, freight operations, and fleet size. • Consider issues associated with disengaging and stopping on highways. • Examine the roles of federal, state, and local governments, as well as industry. The I-10 Corridor Coalition may provide one example. Complete a synthesis of the different corridor studies and pilots. • Examine the perception of drivers and the general public. • Consider the impact on driver turnover and training.

Continued on next page.

Use Cases (continued)

Temporary Traffic Control Event (Work Zones / Incidents)	
Use Case Description	<p>CAVs have challenges when they encounter unexpected events or temporary traffic control that differs from everyday conditions. Examples of these types of events are work zones and incidents. In the near term, work zone location information would be shared with vehicles and fleets to provide advanced warning to CAVs. In addition, incident information recorded at TMCs would be shared with vehicles and fleets. For near-term applications this might be accomplished by sharing with a third party application (e.g., Google, WAZE), directly to equipped vehicles with cellular, or directly with equipped vehicles with DSRC radios. In the long-term, accurate, HD map work-zone data could be shared with CAVs. In addition, detailed information about exact lane closures, traffic queues, and delays could be shared for work zones and lane closures.</p>
Near-Term Issues	<ul style="list-style-type: none"> • Provide information on queue status. • Examine tracking vehicles within a specific environment. • Consider work zone and lane closure details in both the short term and long term) <ul style="list-style-type: none"> • Examine information from pilots in Michigan and Texas. • Examine the need for real-time changes in maps. • Examine the ability to disable AVs or close work zones in the near term. • Consider a classification of work zones to help with approaches. • Develop a model traffic control plan for CAV considerations. • Consider the need for speed harmonization in work zones. • Examine who decides what to do in the case of deviations. • Consider the roles of the state DOT and contractors for quality control.
Long-Term Issues	<ul style="list-style-type: none"> • Determine when Level 4 and Level 5 AVs might need to be disabled. <ul style="list-style-type: none"> • Develop business models considering traffic volume and throughput. • Develop objective measures, performance measures, and quality of service indicators. • Consider issues associated with data flows to and from CAVs. • Consider the need of individual OEMs to disengage. • Examine the data about every component of work zones, including static and dynamic data, and the frequency of update by components. • Examine methods to minimize unnecessary lane closures and the design work zones based on CAVs.

Continued on next page.

Use Cases (continued)

CAVs in Mixed Traffic	
Use Case Description	<p>CAVs will offer improvements in safety, throughput, and congestion. Challenges in the short term include (1) operation and implementation issues, i.e., road signing and marking requirements and standards, lanes designated for CAV movements, driver information on joining and leaving platoons, and digital maps; (2) impact estimation and prediction: existing tools cannot accurately assess CAVs impacts on freeway lane capacity, travel-time reliability, and environmental impacts. This creates difficulties in incorporating CAVs in planning and operations studies; and (3) no guide or standards on required communication means (DSRC versus 5E), platooning configurations.</p> <p>In the longer term with higher penetration, CAVs implementation will generate a large amount of data. Existing TMCs need guidance and resources to store, process, and analyze the data. Furthermore, procedures need to be in place for sharing the data with other agencies and operators. The CAV data provide opportunities for advanced control algorithms (e.g., ramp metering, dynamic lane designation) and management of toll facilities.</p>
Near-Term Issues	<ul style="list-style-type: none"> • Examine the low levels that exist today in a mixed environment. • Consider the need for better signage and lane markings. Examine the need for data on current state of environment. • Consider issues with ramp meters. • There are currently no standards on requirements, such as 5G versus DSRC, and lane markings versus no lane markings. • Consider platooning versus CACC versus harmonization. Examine that low penetration rates may still have benefits to all traffic. • Examine how to inform drivers in platoons and out of platoons. • Explore the use of digital maps.
Long-Term Issues	<ul style="list-style-type: none"> • Consider the issues of data versus penetration rates. • Examine access control based capacity to improve AV levels. • Examine methods for agencies to obtain needed data to augment TMCs. • Consider needs of BRT and transit facilities.

SUGGESTED ACTION ITEMS

- Participants suggested that no significant changes in infrastructure geometry are needed in the near term for CAVs, but that opportunities exist for better planning, road markings, and signing.
- Participants supported continuing the dialogue among OEMs, suppliers, and infrastructure owners and operators.
- Two synthesis topics were identified during the session. One topic focused on summarizing current research on CAVs' use of high-speed controlled access facilities, pilot projects, and deployments. The second topic addressed examining the status of multistate truck platooning pilots and projects.
- The five sponsoring committees will also use the input from the discussions to develop research needs statements.

APPENDIX P

Breakout Session 16: Aftermarket Systems: ADAS Related

ORGANIZERS

Chris Borroni-Bird and Jim Misener, *Qualcomm Technologies Incorporated*

REPORTER

Christopher Borroni-Bird, *Qualcomm Technologies Incorporated*

SESSION FOCUS

The goal of the session was to better understand the role that aftermarket systems may play in accelerating the deployment of AVs. Aftermarket systems can accelerate deployment of AVs while providing safety benefits with a viable business model. Examples of aftermarket systems may include those that provide collision avoidance warnings, train computer vision algorithms, or transmit and receive V2V messages. The session included speakers from technology start-up companies who discussed the benefits and challenges associated with aftermarket system deployment. The speakers and participants discussed possible business models, since aftermarket systems cannot expect to be mandated by government.

PowerPoints of the presentations from Breakout Session 16 (Wednesday afternoon) are available on the AVS17 website at <http://www.automatedvehiclessymposium.org/program/proceedings>.

SESSION SUMMARY

Roger Lanctot, Strategy Analytics, provided an overview of aftermarket systems. Speakers from six start-up companies that are developing aftermarket solutions with a strong ADAS element also participated in a moderated panel session.

Joao Barros, Veniam, noted that AVs will require a fundamentally different networking platform, which must enable vehicles to communicate with each other and share massive amounts of data with the cloud. By deploying and operating mesh networks of connected cars, buses, and trucks in cities like Porto, Singapore, and New York, Veniam was able to establish the first commercial service on top of DSRC-V2X in the 5.9-GHz band and proved that there is a business case for this new kind of infrastructure without public funding by creating revenue generating services based on data.

Barros reported that, currently, Veniam has the largest and most diverse fleet of vehicles that talk with each other on a daily basis in very diverse environments (flat, high-rise, hills, foliage, industrial, etc.). He noted that the key to solving the data tsunami that will be generated

by AVs is to combine multinet network mesh architectures, smart (and local) data management, and, most importantly, low-latency fail-safe vehicle-to-cloud platforms.

Barros said that, ultimately, the utility of vehicles can be increased by enabling them to be more than simply machines that carry people and goods from one place to the other. Veniam mesh-connected vehicles expand wireless Internet access, improve the quality or experience of mobility services (through richer connectivity and vehicle data sets), and gather massive amounts of urban data for a variety of smart city applications powered by data APIs.

Stefan Heck reported that Nauto provides safer driving for current and new vehicles, and future AVs. For aftermarket use case, the Nauto smart AI dashcam records and uploads risky events to the cloud. In the case of a collision where the driver is not at fault, the video provides proof of innocence. He noted that the risky events can also be used as coaching material for risky drivers. He said that drivers improve because they see hidden events and when drivers improve, crashes decline. In the driver spectrum, for the 20% safest drivers, their driving behavior can be used as training data for building into AVs.

Paul Sakamoto of Savari, discussed that V2X consists of vehicles, infrastructure, and pedestrians with a real-time connection for mutual awareness. Improving safety, enhancing the economy and minimized environmental impacts is the focus of Savari. He suggested that the first big deployment of V2X technology will occur in new vehicles beginning around 2019 to 2020. He said that although this will be a promising beginning, it will take a long time (estimated at over 10 years) to approach a near 100% penetration of V2X units in the United States, with perhaps a similar absorption rate in other industrialized economies given the wear-out or replacement cycle of various vehicles.

Cory James Hohs of HAAS Alert, said that the company is solving the problem of needing to alert motorists of what is ahead in real-time based not only on onboard vehicle sensors but by using cellular networks to inform motorists proactively with their mobile V2V platform. He said that as a first market approach, the company is working with public safety and first responders to alert CVs, navigation, traffic, and smart city grids when first responders are en route. This approach allows the company to generate unique datasets that can pass through the HAAS Alert Safety Cloud to multiple distribution channels. He noted that by using cellular, there is the added advantage of public safety mandates around FirstNet, and other preemption regulation and offerings that are to come as IoT, connected vehicle, and AV growth continues.

Hohs said that in the United States alone, there are approximately 60,000 emergency vehicle collisions each year with police officers and that firefighters have a higher risk of death and injury traveling to the scene of an incident than at the scene itself. Insurers of municipalities pay out millions in coverages associated with emergency vehicle accidents. In addition, there is no dataset that provides real-time dynamic locations of emergency vehicles, let alone other cautionary situations that could provide useful alerts to drivers.

Hohs discussed the need to be cost effective, scalable, and deployable today. Haas and other businesses need to solve data problems for cities. He noted that the Haas approach requires no costly infrastructure for municipalities that would require them to implement costly and timely V2V–V2X supporting hardware and software. The HAAS Alert Safety Cloud can receive data from any sensor or input and can push alerts or messages to motorists in real time, without the need for crowd sourcing. The mobile V2V technology, the Safety Cloud data transfer, along with the integrated messaging platform, permits a simple and scalable model for cities looking to increase public safety, urban mobility, intelligent traffic, smart city, and other applications.

- Participants discussed that data collection is a key hidden value beneath the aftermarket device's basic value proposition, but that challenges remain to OEMs in the cost of collection, liability for data, and finding effective ways to monetize. The possibility of providing free data plan in exchange for vehicle data was discussed by participants.
- Some participants noted that cameras are sensors with the highest growth, partly driven by regulations and by multifunctional applications (even if not perfect solution) with software updates. It was suggested by some participants that V2X is the only other sensor that is likely to be integrated as an aftermarket device. V2X, unlike sensors, provides information, not just data.
- Participants discussed aftermarket systems that can predict crashes and prevent them, such as Waycare and Banjo start-ups, are “faster to dashboard” and can bring the latest in wireless connectivity. The path to market for these devices may be through government (local DOTs) or fleets to address local problems with fast solutions. Insurers may give reductions to fleets for ADAS devices, but not for private users with personal automobiles.
- Participants discussed if aftermarket systems should be standalone or embedded with vehicle's infotainment system as a refinement. Both approaches are viable, but standalone aftermarket devices are much more prevalent.
- Participants discussed that AI should learn from the best drivers (20% of driver population), not just “obey rules of the road” e.g., crossing the middle line to pass a cyclist. AI should take advantage of all the available capabilities that humans do not have.
- Participants discussed that DSRC in smartphones is challenged because Wi-Fi radio has to be 10 times more powerful.
- Participants discussed that the current wireless infrastructure is ill-suited to transport 1 TB/vehicle per day from connected vehicles and that there may be a need for Wi-Fi and DSRC in certain locations to minimize cellular usage, as most data can be delay-tolerant. Telecom operators may be willing to install DSRC in RSUs to offset traffic loads. V2V mesh software updates can be 10 times cheaper than using 4G. It was noted that most aftermarket devices are single function and rely on cellular (dictating only small amounts of data) and not upgradeable.

SUGGESTED ACTION ITEMS

- Participants identified the need to define if there is there an aftermarket for safety systems and how effective these systems can be when fitted in postproduction.
- Participants suggested the need to examine the optimization of wireless networks based on probable data uploading–downloading requirements.
- Participants discussed if cellular technology could play a role in safety and how and when will it be tested side-by-side with DSRC. It was noted that Nauto, Nexar, and Haas Alert have made the case for leveraging existing cellular technology for enhancing safe driving. Participants also discussed if the aftermarket will prove to be an effective path to market for DSRC. Veniam, Savari, and Peloton have made the case for aftermarket fitment of DSRC technology for both enterprise and safety applications.
- Participants noted that aftermarket devices need to be multi-functional, multinetwork capable, and upgradeable. It was further noted that business and technical challenges need to be addressed with data collection. A critical point of discussion was the volume of data that will be shared in the future and the role direct communications will play, whether using cellular or

DSRC. Exploring what the automotive industry can learn from the fleet sector in terms of required fitment of collision avoidance systems was suggested as beneficial.

- It was noted that at the core of all of these solutions is the extraction of data via cellular or DSRC to enable the aggregation, interpretation, and sharing of data between vehicles—both in real-time and as when convenient to lower costs.

- Possible research topics related to the adoption of V2X were discussed. Researching, developing, and distributing a model for the market uptake of V2X, assuming it is being installed exclusively in new cars, should include variables for government mandates for completeness around the world. Researching, developing, and distributing a model for the market uptake of V2X, assuming a variety of aftermarket V2X devices are made available, should include variables such as a government mandate requiring various levels of capability, direct cost allocation (consumer only, insurance company trade-off with consumer, and shared cost with traffic authority). Other factors to consider include the level of professional installation required versus capability versus cost (assumed higher cost and difficulty leads to lower adoption rate), the factors that will draw consumers to desire such devices, and possible factors that will be negative for aftermarket adoption.

- Additional research project discussed by participants was developing a detailed model of the impact of ASD at different levels of absorption and the potential impacts of different sets of applications. For example, Intersection Motion Assist (blind corner) apps may have a different impact than FCA and EEBL.

APPENDIX Q

Breakout Session 17: Safety Assurance of Automated Vehicles

ORGANIZERS

Hermann Winner, *Technische Universität Darmstadt (Germany), Institute of Automotive Engineering, Chair*; and Ching-Yao Chan, *California PATH, UC Berkeley, Co-Chair*

REPORTERS

Yi-Ta Chuang, Pin Wang, and Yi He, *California PATH, UC Berkeley*

SESSION FOCUS

This session focused on advancing the discussion of SAAVs, which is an unsolved problem for the introduction of automated driving. The 2016 AVS included experts of different countries presenting aspects and approaches of SAAVs. Those contributions and discussions led to the identification of key issues, which was the focus of the 2017 AVS breakout session on Safety Assurance.

Seven presentations were given in two sub-sessions. The panel discussions at the end of the two sub-sessions encompassed a broader framework for exchange of different perspectives and discussions with participants. The presentations by invited speakers provided an overview of the safety assurance approaches and respective methods. Participants obtained an understanding of the different methods and engaged in discussions to convey different perspectives. The panel discussion identified the next steps for forming a strategy to achieve the goals and objectives of safety assurance.

SUB-SESSION 1: TECHNICAL APPROACHES ON SAFETY ASSURANCE

Creating a Reference for Automated Driving: The Approach Followed by PEGASUS

Lutz Eckstein, *RWTH Aachen University (Germany), Institute for Automotive Engineering*

Eckstein discussed that since absolute safety does not exist, a commonly accepted safety reference for automated driving is needed. He described the systematic approach followed by the German project PEGASUS and pointed out how this reference can be used during the development process to assure the safety of automated driving functionalities. He described the required tool chain and possible models for cooperation between stakeholders.

He noted that successful automated driving requires a holistic tool chain and relevant simulation scenarios that can be re-used. Further, he noted that a database of relevant traffic

scenarios is important in the loop-based validation and development process. He also discussed that international collaborations are needed to achieve automated driving.

Software-Defined Intra-Vehicular Networking for Autonomy

Edward R. Griffor, *National Institute of Standards and Technology; Associate Director, Smart Grid and Cyber Physical Systems Program Office*

Griffor described efforts at the National Institute of Standards and Technology using SDN to develop this new approach to vehicle networking, develop a simulation environment, and test the approach. Griffor described SDN for Intra-Vehicular Networks, bringing SDN's traffic prioritization and resource management capabilities to make better use of the available bandwidth offered by vehicular buses and to enable the improved safety, security, and reliability of automotive networks needed for AVs. He noted that this approach has been tested for key AV systems. He discussed that all safety concerns should be applied to AVs, and highlighted the cyber security elements of confidentiality, integrity, and availability. He noted that critical safety properties are preserved through change in the network and that physical resource management is moved to virtual SDN. Verification occurs in a virtual environment.

Validation of AV Software by Simulation

Chad Partridge, *CEO of Metamoto, Inc., a start-up specializing in test and validation of autonomous systems*

Partridge discussed that satisfying safety requirements for AVs embodied in software and deep learning was a massive challenge of scale. He noted that tests across many thousands of parameterized scenarios must be run during development, as well as every time vehicle software, sensors, and infrastructure change. To realize this need, he noted that physical tests are supplemented with extensive on-demand simulation, which must validate the integrity of the software before a vehicle is put into operation. He suggested that traditional automotive simulation tools are not up to the task of this scale of simulation. He further suggested that, mature agile software engineering approaches, especially those involving continuous test and integration, provide a proven way forward. He discussed topics surrounding evolving AV simulation best practices. He suggested that it was not possible to evaluate the AV software by physical cases and that simulations should play an important role in the validation of the AV software. Problems with real-world tests discussed included highly complex operating conditions and innumerable test cases and the cost availability and accuracy of real world data. Collaboration, computing resources, and disciplined requirements management are needed to meet these challenges.

Proving Ground Testing

John Maddox, *American Center of Mobility*

Maddox described the current plans for the American Center of Mobility in the Detroit area, which includes a proving ground for testing AVs. He noted that safe validation must include a structured combination of three methodologies: simulation, track testing, and on-road testing. He also noted that significant technical and policy challenges remain. He suggested that industry and

government need to collaborate on standards, technical expertise, voluntary standards, and regulation.

PANEL DISCUSSION 1

Question: How to combine the three procedures to certify the lifetime learning verification to assure the safety of AVs and the transition between AI and human driver?

Discussion: Participants discussed continuously reporting the behaviors of the AVs to clouds and improving their AI model and downloading the data to the vehicles.

Question: Is there a security risk if the AV components are open the public?

Discussion: Participants discussed defining the security principles to identify the importance of the components. Regulations are needed on what kinds of components will be made public. It was suggested that the core component of the vehicle should not be open to the outside.

Question: Who is responsible for monitoring the certification of the downloading activities from the AVs?

Discussion: Participants suggested that the vehicle vendors should be responsible to ensure the certification.

Question: Concerning the verification of the core safety, from the architecture side, does it mean that if the AI model changes, a reverification is needed?

Discussion: Participants discussed trying to constrain the functional components to restrict the possibility of the change of the system.

Question: Are there some suggested scenarios as references for simulation testing?

Discussion: Participants suggested collecting different scenarios, obtaining similar information, and documenting the drivers' behavior with a balance between drivers and vehicles.

Question: How to deal with the gap between simulation in the virtual world and testing in the real world?

Discussion: Participants discussed that the comparative performance needs to be correctly understood, which remains an open issue.

Question: How to get the referenced scenarios?

Discussion: Participants discussed that one option is to use computers to create the scenarios and using communication resource to do intelligent test running. The results could then guide what scenarios are tested next.

SUBSESSION 2: SOCIETAL PERSPECTIVES ON SAFETY ASSURANCE

Customer Expectation of AVs

Ryan Harrington, *Exponent, Inc.*

Harrington suggested that the media frenzy surrounding AV technology and AVs seems to be shaping unrealistic consumer expectations, at least for near-term deployments. This is compounded by the fact that increased technology complexity drives larger differences between consumer understanding and reality, leading to potential misuse. He discussed possible roles for instructions and warnings to play in setting realistic consumer expectations and how consumer education and marketing can be used to shape more realistic expectations and more successful AV deployments.

A New Age in Public Sector Safety Assurance

Shawn Kimmel, *Lead Engineering, Booz Allen Hamilton.*

Kimmel discussed that an advanced design system (ADS) may present many challenges to existing vehicle testing and certification approaches in the United States. He noted that the U.S. DOT is undertaking research to identify potential testing frameworks and standards to support ADS safety assurance. He discussed research efforts to develop objective and repeatable test cases and scenarios for HAVs. Factors that are considered in test case development include ADS functionality, ODD, object and event detection and response requirements, and fail-safe and fail-operational mechanisms. He highlighted an analysis of the technical standards landscape, which includes identifying the needs and gaps in technical standards for safety assurance. He noted that multifaceted testing architecture (simulation, closed test tracks, and open test road) will be the next step in the verification of the safety assurance of the AVs.

SAE V&V Committee

Dan Bartz, *Fiat Chrysler Automobiles.*

Bartz discussed the ability to avoid a full verification when a new functional component is added, noting that one suggested approach was that with the lower levels of components already verified, only the newly added component needs to be verified.

PANEL DISCUSSION 2

Question: In the driving testing scenario, should driver behavior be included in the validation?

Discussion: Participants discussed that in the design phase, human factors should be taken into account and that the validation phase focuses on the technical aspects. It was further discussed that the V2V upgrade is more difficult than updates on individual vehicles and that system changes need to consider consumer reaction; e.g., people may want to try out new functions without really understanding how to use them. Considering these issues in a product design way would be a safer approach.

Question: Scenarios used during tests may be different from the actual scenarios?

Discussion: Participants suggested that there may not be that much of a difference. Scenarios can come from previous crash incidents. The methodology comes from research institutes, industry, and other specific sources. It was suggested that the data needed to establish a specific scenario include dataset accumulations and experiences.

Key Findings for the SAAV Breakout Session

- Participants noted that safety assurance relies on simulation, proving grounds, and drive tests for safety validation.
- Participants suggested that scenario and database sharing opens an efficient way for safety assurance and standards on the methodology.
- Participants also noted that there is a high uncertainty about how AVs will be deployed and accepted by society in future.

SUGGESTED ACTION ITEMS

- Participants suggested a follow-up effort focusing on encouraging the interesting and grand challenges of SAAVs with young researchers.
- Participants stressed the importance of maintaining the momentum from the breakout session and the interested parties and stakeholders, so that continuing research and developments can benefit the greater community.
- Participants suggested a follow-up activity of promoting the sharing of driving scenarios and databases among the various stakeholders.
- Participants discussed the need for researchers and stakeholders to face these challenges. Communicating this need to diverse stakeholder groups was suggested by participants as a possible follow-up activity.
- Participants suggested the ongoing follow-up activity of continuing to obtain a better understanding of the challenges associated with AV safety assurance.
- Participants discussed the importance of maintaining the momentum of the current gathering of interested parties and stakeholders.

APPENDIX R

Breakout Session 18: Reading the Road Ahead *Infrastructure Readiness*

ORGANIZER

Scott O. Kuznicki, *Dubai Office of Transport Group*

In Cooperation With

Paul Carlson, *Texas A&M Transportation Institute*; Brian Watson, *American Traffic Safety Services Association*; and Robert Dingess, *Mercer Strategic Alliance*

REPORTERS

Abby Morgan and Scott O. Kuznicki, *Dubai Office of Transpo Group*

SESSION FOCUS

This session examined machine vision and traffic control devices to initiate the development of a framework for implementing a levels of readiness evaluation system and information clearinghouse. The workshop began with participants assessing the capabilities of SAE Levels of Automation and common machine vision systems in the context of the roadway environment, including signing and pavement markings. To enhance coordination between suppliers and vehicle manufacturers in the development of traffic control devices that are highly compatible with AV machine vision systems, participants discussed a capabilities matrix for machine vision systems and a corresponding recommendation for roadway readiness based on traffic control device applications and condition.

Goals of the session included:

- Determining the needs of traffic control device adaptation for machine vision systems;
- Learning about machine vision system shortfalls and planned improvements;
- Better defining the role of mapping in navigation and infrastructure identification;
- Identifying the state of readiness initiatives worldwide, focusing on Colorado and the EU as examples; and
- Determining a path forward for developing a readiness framework in North America.

SESSION SUMMARY

Key Questions for Consideration

- What's the minimum amount you think you need to be ready for AVs?
- What would you like to do?
- What needs to be done?

WORLDWIDE STATE OF MACHINE VISION SYSTEMS

Ambiguous Infrastructure: A Worldwide Perspective

Scott Kuznicki, *Dubai Office of Transpo Group* –

- Logical inconsistencies may confuse human drivers or AI (inconsistent signage, placement, application, or pavement markings).

V2X Applications for Intersections

Jaap Vreeswijk, *MAP Traffic Management*

- ECE H2020 call ART 05, 2016.
- MAVEN (MG3.6a).
- TRANSAID (ART-05).
- Connected automated driving requires intelligent environment with infrastructure.

Facilitating Automated Driving: The EU EIP Experience

Tom Alkim, *Dutch Road Authority*

- EU EIP—Facilitating Automated Driving—sa4.2: Provide road map and action plan for road operators.
 - <http://eip.its-platform.eu/activities/sa-42-facilitating-automated-driving>.
 - Adding elements versus Leaving out elements - Until you have 100% AV penetration, you will still be designing for the manual driver.

The Role of Mapping in Automated Driving: Capturing Infrastructure for the Operator

Monali Shah, *HERE*

- HERE is shifting from maps for navigation to an open learning network.
- SENSORIS: data specification for crowd sourcing data common platform.

CDOT RoadX Program and Preparing for AVs

Peter Kozinski, *Colorado DOT* –

- Safety and mobility are driving factors for Colorado DOT's CV/AV efforts.
- Mapped Colorado DOT's connected road classification system to prioritize improvements.
- Partnered with Panasonic on V2X.
- Interoperability is key and must be planned for from the start.

WORKSHOP: MACHINE VISION AND TRAFFIC CONTROL DEVICES

Smart Work Zones for the AV Environment

Joe Jeffrey, *presenting for Ross Sheckler, iCone Products*

Work zone maps change every day.

- Controlled, flagger controlled, uncontrolled, and mobile works zones will have different needs. For example, uncontrolled work zones are rarely reported or mapped (utility work).
- iCone is directly streaming all construction data to Waze and HERE, including activity status, message board messages, and queue speeds. Next, flagger locations, worker locations, and crossing guard locations.
- Discussion: Knowing the location of a work zone is important, but you also need to know what to do.

Signs and Lines of the Future

Ken Smith, *3M Corporation*

- Infrastructure (signs, lines, etc.) plays key role in successful migration to CAVs.
- Machine-readable pavement markings; wet reflective pavement markings.
- Machine-readable signage: testing infrared reflective 2D barcode mounted on signs.
- Real-world global evaluation to support technology development and assessment for existing and evolving vehicle sensors.

Hybrid Infrastructure for Automated Driving

Panagiotis Lytrivis, *I-Sense Group*

- INFRAMIX Project (website: www.inframix.eu; Twitter: @inframix).
- Infrastructure is important to support transition period and mixed traffic scenarios.
- Hybrid = physical + digital infrastructure.
- Physical infrastructure needs to be advanced and affordable.
- Digital infrastructure integrates multiple geo-located information layers from static to dynamic.
- Infrastructure classification scheme. Link attribute needs to different levels of AVs.

- <http://i-sense.iccs.gr/>.

Questions and Answers

Brian Watson, *American Traffic Safety Services Association*, moderator

- Who should control the reporting of work zone changes in the automated environment? Joe Jeffrey: Must happen at the work zone level, because work zones are fluid and require accurate, real-time information reporting. It is not yet clear who is responsible for verifying accuracy of reporting data.

- What will hybrid infrastructure look like in the short and long term? Panagiotis Lytrivis: Today: need the same information communicated from visual and electronic infrastructure. Future: need for pavement markings and signs is unknown. Think of future needs when designing today, so that our infrastructure will be useful for lifecycle.

- Is it too early to think about redesigning our infrastructure for an unknown or far-off future, or should we focus on improving what we have today?

WORKSHOP: DEVELOPING A LEVEL OF READINESS FRAMEWORK

Participants discussed the following topics.

Infrastructure Types

- Visible Invisible
- Active Passive
- Secured Open
- Proven Nascent
- Existing Proposed
- Pervasive Rare

Issues

- Maintaining interoperability with humans.
- ODD definition (roadway, weather, safety performance).
- Limited correlation with SAE Levels of Automation.
- Multifaceted criteria with no single grade.
- Funding and priorities.
- Changing capabilities of vehicle automation.
- Fusing different data sources.
- Guidance or standards for traffic control devices and uses; one challenge is that MUTCD updates are not able to keep up with the speed of changing technology.
- Differentiate between digital and physical infrastructure.
- Do safety/crash modification factor changes that are intended to call attention to drivers become a limitation to the machines?

Needs and Changes for Traffic Control Devices

- Is there a need to provide consistent signage?
 - Any change that is made has the potential toward liability exposure for an agency.
- Is the system we are proposing consistent with what we know works today?
 - Washington State DOT has decided to move away from standardization toward context-sensitive use. Minimalist approach to design.
 - GPS dependency may reduce the need for guide signs in the future when a map is accurate.
 - Once a network is mapped, signs and markings will not be needed for routing algorithms. Sign changes will be a more important trigger than a missing sign.
 - Agencies will still need to maintain signage if it is needed to instruct other road users, pedestrians, bicyclists, and non-AVs, but maybe our signs change to target non-auto users instead of autos.
 - Agencies may outsource signing inventory and updating.
 - What information is machine vision trying to obtain from our signs and how is this information being used? We know they are reading speed limit signs, but what other information are they looking for from a sign. It is an input to ML at this point.
- Geofencing will be key to supporting AVs.
- How do we respond to the need to provide good pavement markings in the correct location, correct pattern, and consistently maintained?
 - Daytime is harder than nighttime to read.
 - NCHRP is working to provide agencies with concrete guidance for markings.
 - Before we spend money on maintaining pavement markings more frequently, do we know if the current lane-marking requirements are good enough for machine vision?
 - If we think pavement markings are critical to machine vision, what happens when it snows?
 - Roadway guidance is not simply pavement markings. It is also retroreflective pavement markings, etc. Consider them all as one system.
- Need to tie ROI to broad network for agencies to justify their investments.
- Need multijurisdictional groups to understand the target of what they need to work toward. Road operators need to get this information from the OEMs/suppliers.
- Maintain your best practices to support drivers today. AVs will be able to operate under those conditions.

Participants discussed if there is there a need to classify corridors based on a handoff between machine and human driving. Most participants felt that this might be needed at some point, but OEMs were not ready to specify these needs yet as technology is still evolving and learning.

Participants discussed the need to recognize that infrastructure is not the same as understanding what to do in different situations. The context is needed to understand both.

Participants discussed if states will invest in AVs when the adoption of this technology is not yet known.

SUMMARY OF KEY FINDINGS AND LESSONS LEARNED

- Participants discussed that consistency and logical application may be more important than compliance.
- Speakers and participants discussed that machine vision manufacturers expect use of best and established practices with traffic control devices.
- Participants discussed that shortfalls exist in machine vision capabilities relative to more complex environments.
- Participants discussed that the development of a readiness framework goes beyond the Level of Automation or Operating Domain. Participants further suggested that readiness ratings will require multicriteria topology and uniform assessment practices.

SUGGESTED ACTION ITEMS

The expected work products of this session were anticipated to be a recommended set of research problem statements for synthesis and practice evaluations and also a research problem statement for the development of an information clearinghouse for the classification of machine vision systems and roadway segment properties.

However, it was clear from the discussion that most agencies are investing resources in CV preparation, but not necessarily for AV preparation. Participants recognized that AV preparation should be a priority, however, because AV operation without any supporting CV infrastructure was already occurring. Another takeaway was that most agency and consultant representatives reported knowing little about the machine vision system operational principles, the limitations of those systems, or the manufacturer efforts to enhance the systems' capabilities to make up for shortcomings in traffic control device infrastructure.

The following action items were suggested by participants.

- Participants discussed that most agency personnel and consultants do not have an extensive understanding of machine vision systems. As a result, participants suggested that it was important to connect machine vision experts with transportation system management and operations engineers, traffic design engineers, and traffic control device manufacturers.
- Participants noted the need to identify shortcomings on both sides and collaborate on filling identified gaps. Planning a "Sensors 101" plenary panel for the 2018 AVS was supported by participants.
- Participants suggested that research using the human factors primacy triangle to better understand driving tasks would be beneficial. The research could examine driver assistance devices as a means of countering human shortfalls. It was also suggested that delineation was more important than signing, excepting regulatory signs in low-information environments.
- Participants noted that 2009 was a long time ago and that the MUTCD (23 CFR 655) is not timely enough to set standards for machine vision applications. Developing new consistency criteria that focuses on critical devices was supported to address these deficiencies.
- Participants suggested that convening an independent consortium to develop readiness criteria, assessment methodologies, and rating and needs identification databases would be beneficial. These items are key in determining the minimum investments required.

Items to consider with this approach included identifying possible risks of “stamp of approval” in tort liability and identifying key components of an interim need to identify hand-off needs and locations for various domains and regimes.

APPENDIX S

Breakout Session 19: Shark Tank—Change Is Coming *Who Will Survive?*

ORGANIZERS

Richard Mudge, *Compass Transportation and Technology*; Alain Kornhauser, *Princeton University*; Amitai Bin-Nun, *Securing America's Future Energy*; Alan Chachich, *U.S. DOT Volpe Center*; Reinhard Pfliegl, *A3PS*; David Pickerall, *Smart and Connected Transportation*; and Scott Smith, *U.S. DOT Volpe Center*

REPORTERS

Jonathan Koopmann, *U.S. DOT Volpe Center*

SESSION FOCUS

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.

SESSION SUMMARY

AVs and shared mobility provide classic examples of disruptive innovation. Change will be nonlinear in nature, it will be difficult to predict impacts with precision, and it will probably generate new markets and new ways to provide traditional transportation services. Implications cover economic and social changes, well beyond those of traditional transportation investments.

Four topics were addressed by speakers with the sharks providing review comments and participants discussing possible impacts.

Sharks (Commentators)

- Alain Kornhauser, Princeton University;
- Jim Scheinman, Maven Ventures;
- Iain Forbes, Head of the Centre for CAV; UK Ministry of Transportation;
- Chris Gerdes, Center for Automotive Research at Stanford;
- Reinhard Pfliegl, A3PS; and
- Brad Templeton, Singularity University.

TOPIC ONE: THE END OF TRAFFIC CONGESTION

Reduced crashes and shorter headways (platoons) should increase the effective capacity of expressways and other roads. The U.S. DOT report, *Beyond Traffic*, mentioned a possible five-fold increase in road capacity. Even less dramatic changes would have major implications for economics (improved access to labor/jobs and markets); finance (reduced need for public spending); and land use (encourage increased VMT). This topic focused on economic, social, and environmental implications rather than traffic simulation models.

Opening Presentation

Richard Mudge, *Compass Transportation and Technology Inc.*

- Proposed reasons traffic congestion could be reduced, especially fewer crashes.
- Reduced headways will significantly increase throughput – probably requires some level of connection between vehicles.
- Shared vehicles will increase passengers per vehicle.
- Congestion will occur in a much more predictable manner so the public can avoid it more easily.

Sharks' Response and Participant Discussion

- Induced demand could be an issue, which would offset reduced congestion, creating environmental disutility. On the other hand, increased demand could reflect improved economic and social access.
- VMT will increase due to improved convenience during congestion. Additionally, an increase probably will occur due to improved accessibility for elderly and handicapped individuals.
- Solutions exist through metering and congestion pricing. Related concepts such as reservations to use roadways at specific times (based on payments or a lottery system).
- New roadway uses will occur such as double parking and having the car move automatically when needed. These uses could reduce congestion.
- Demand will exist to right size a trip in terms of shared use and vehicle sizing to match number of travelers or trip purpose.
- Costs could drop below 50 cents per vehicle mile (even 25 cents was mentioned), which will drive the possibility of sharing. However, if the cost for a single person trip is incremental versus a shared trip, it will be a tough sell for shared trips.
- Technology may help provide the solution if a critical mass of users and business models exists.
- Congestion management incentives need to have a significant appeal to encourage the option through methods other than coercion or poor service.
- There will be a greater willingness to accept longer drives (in time and distance) when travelers can do other things (eat, read, sleep, use a device).
- Additional VMT could result in the need for more roadway maintenance.
- There will still be a need to pay for transportation system maintenance; new funding streams will be needed.

- It will be critical to think about access for all segments of society, especially if fleets are run by companies and not government agencies.
- Electric cars are the probable choice for AV fleet use, particularly in urban areas. This has positive implications for the environment, but a negative impact for traditional roadway finance.

TOPIC TWO: FREIGHT REVOLUTION

Truck platoons have been tested and appear on the verge of operation. This session will not focus on energy savings such as from truck trains where each truck has a driver, but rather on driverless trucks. These offer the opportunity to travel long distances without a stop, such as coast-to-coast in 2 days. High-speed intercity passenger service was also mentioned.

Opening Presentation

Steve Boyd, *Peloton Technologies*

- Begin with Level 1 AV while working toward higher-level automation.
- This technology could help address the driver shortage issue by helping make truck driving a more appealing profession.

Sharks' Response and Participant Discussion

- AV solutions are not limited to 53-ft trailers; new sizes and uses could change the trucking landscape and operational models significantly.
- Markets are changing for interactions with business and expectations of service (see Amazon's purchase of Whole Foods).
- The trucking industry is ripe for change, but it is a long standing and entrenched industry.
- Where do rail and other modes of transportation fit into this discussion? Reduced costs for truck transport (particularly for full driverless vehicles) could increase the market share for trucks and reduce the share for rail.
- Why is the prediction of how long drivers will be needed different between cars and trucks? The consensus seems to be that people will shift to driverless vehicles sooner, particularly in urban areas.
- One of the main obstacles to truck automation is public safety concerns.
- Truck platooning should be discussed with mixed fleets and for other applications like improving network efficiency through speed harmonization.

TOPIC THREE: WILL STATE AND LOCAL TRANSPORT AGENCIES FADE AWAY?

Does the growth of AVs and shared mobility leave state DOTs and metropolitan planning organizations with less to do? CAVs require little if any financial support from public agencies. That is, deployment will occur largely based on market forces.

Opening Presentation

Baruch Feigenbaum, *Reason Foundation*

Feigenbaum proposed the following concepts about AV's impacts over the next 30 to 50 years:

- State DOTs:
 - Provide financing and tools rather than funding.
 - Build fewer roadways and use more contract maintenance.
 - 511 systems will phase out in favor of other information services.
 - Less contracts and management.
- Transit:
 - Less purchase of vehicles; most will be private purchases.
 - Contract out most of the transit network operation.
 - Fewer operators due to automation.
 - Less maintenance required and it will be performed by contract.

Sharks' Response and Participant Discussion

- Why aren't transit agencies trying to make a significant change to get a larger mode share?
 - First mile and last mile may not address the breadth of the impending change.
 - Transit agencies are not seeing the pending disruption. Part of what is important to cause disruption is deception—it does not appear disruptive to everyone, or else the incumbents would also be in this space.
 - Discussion of the GM acquisition of Cruise Automation as a transformation of the business model—more than half existing OEMs will no longer be in business in the future.
 - Paratransit will likely be the first place we see new contracted and new business models.
 - Could there be a hybrid model where government transit agencies offer incentives for contracting and they coordinate but do not operate the system?
 - Transit systems do not recover their costs but provide equity; how will that change with TNCs and new operating models?
 - State DOTs are already moving significantly toward more contracting, but what will be the relationship between the new fleet managers and roadway operators?
 - The number and extent of mobility provider's coverage may put them in a place where they also begin to cover infrastructure management.
 - There are risks of monopolies with limited mobility providers.

TOPIC FOUR: NO ONE OWNS CARS ANY MORE

A growing number of people support the idea that the combination of AVs, shared mobility, and reduced interest in driving will eliminate automobile ownership, at least in urban areas. This is linked with the MaaS concept. A recent MIT study reported that 3,000 vehicles were enough to handle all the traffic in Manhattan.

Opening Presentation

Susan Shaheen, *Director of Innovative Mobility Research, University of California at Berkeley*

- Foundation of argument for decreased car ownership:
 - Trends of millennials—greater use of shared economy—access trumps ownership.
 - Enabled by sharing, electrification, connected technologies, and automation.
 - Land use, built environment, and usage determine user need for car ownership.
 - Affected by
 - Availability and affordability of multimodal options;
 - Network effect and right-scaling of alternative vehicle services;
 - High reliability with both on-demand and reliability;
 - Availability of real-time information car-ownership services; and
 - Policy to enable car-ownership alternatives.

Sharks Response and Participant Discussion

- This approach will not work for all places all the time.
- This approach will drive down the number of cars per household.
- People will still want to have toys (fast cars).
- It is probable that the younger generation will buy into this concept earlier.
- Some people will still want to express their individuality through car ownership.
- There will still be unique needs to transport ancillary items.
- How will this impact PMT?
- What will be the replacement level of vehicles in urban areas? Suburban areas?
- There is a need to create an ecosystem around the shared economy that supports all the needs of individuals through their different phases of life.
 - What are the impacts of single-occupancy vehicles on bikesharing and walking?
 - What are the reasons for so strongly tying electrification to automation?

Suggested Action Items

- Participants supported continuing this type of session at the 2018 AVS. The open discussion of the topics by both the speakers and the panelists was noted as very beneficial by participants.
 - Possible research topics identified by speakers, panelists, and participants during the session included examining the potential impacts of shared AVs and mobility services on VMT and public transit, exploring the evolving roles of transportation agencies, and assessing the impacts of automated trucks on public safety.

APPENDIX T

Breakout Session 20: Making Automation Work for Cities

ORGANIZERS

Siegfried Rupprecht, *Rupprecht Consult*; Jane Lappin, *TRI*; Dirk Heinrichs, *Institute of Transport Research – German Aerospace Center*; Scott Smith, *U.S. DOT, Volpe Center*; Ellen Partridge, *University of Chicago, Booth School of Business*; Amitai Bin-Nun, *Securing America’s Future Energy*; Karen Vancluysen, *POLIS*; and Steve Buckley, *WSP Parsons Brinckerhoff*

REPORTERS

Siegfried Rupprecht, *Rupprecht Consult*; Scott Smith, *U.S. DOT, Volpe Center*; and Dirk Heinrichs, *Institute of Transport Research—German Aerospace Center*

SESSION FOCUS

The session examined the status of planning and implementing automation in cities and metropolitan areas in the United States and in Europe from an urban policy perspective. Breakout session participants discussed measures to create an enabling policy framework for transport automation that also contributes to meeting key urban policy goals. The first part of the session featured five speakers from the cities of Boston, San Francisco, Helmond, and Milton Keynes, and Waste Management, Inc. The second part of the session included six presentations from public agency and business representatives. The third part of the session was a panel discussion involving all the speakers.

PowerPoints of most of the presentations are available on the AUVSI website at <http://www.automatedvehiclessymposium.org/avs2017/program/proceedings>.

PART 1: FORGING THE SILVER BULLET: HOW TO PREPARE FOR A NEW GENERATION OF SHARED COLLECTIVE TRANSPORT SERVICES WHILE ENSURING COMPLIANCE WITH KEY URBAN POLICIES?

Siegfried Rupprecht, *Rupprecht Consult*, moderator

Making Automation Work in Boston

Kristopher Carter, *City of Boston, Mayor’s Office of New Urban Mechanics*

Carter noted that the Boston Mayor’s Office of New Urban Mechanics focuses on innovative ideas and “learning as we go.” He noted that Boston had recently completed a citizen engagement process (GoBoston2030). Citizens voiced interest in access (connecting

neighborhoods for all modes), safety (reducing crashes), and reliability (consistent TTs). He noted that the interest in AVs is to support these goals. Equity was also mentioned, as some neighborhoods are not well served by transit.

Carter noted that Boston is the test site of a major automation trial supported by the World Economic Forum. Boston was selected due to its strong political support (Executive Orders supporting automation from both the governor and mayor), challenging winter weather, unique road infrastructure, pedestrian/bicycle/motorist behavior, and local talent. Efforts began in February 2016 with the Smart City application that was not selected as a finalist by the U.S. DOT, but then support was received from the World Economic Forum.

Carter reported that the companies involved in the test are following a simple reporting process, have agreed to participate in public events, and are not making any financial transfers. He noted that lessons learned include, the city should develop a clear vision; strong relationships are critical for trust and collaboration; do not let the perfect be the enemy of the good; iterate.

More information is available at www.boston.gov/boston-av.

Making Automation Work in San Francisco

Tilly Chang, *SFCTA*

Chang is Executive Director of the SFCTA. She noted that demand for transportation in San Francisco is increasing. People want walkable, transit-oriented streets with technology-enabled, clean transport.

Chang reported that the development of 8,000 housing units on Treasure Island prompted interest in a MaaS concept based on AVs. This approach requires significant public engagement, public-private and public-public partnerships. Shared AVs are part of the transit-land use development plans. Technology needs to match the goals of the city, which focuses on “Transit first.”

Chang said that the city’s role in integrating modes on a common platform is yet to be determined. It is important to bring the public layers to the table first; city government is important as the convener. She suggested that ultimately, cities may need to move away from a gas tax and embark on a VMT tax.

Chang suggested that Uber and Lyft appear to be reducing the use of transit in some areas. Bay Area Rapid Transit trips are lower according to recent research. A research project is currently investigating potential impacts further.

Automated Transport, Curse or Blessing? A small Cities’ View

Gert Blom, *City of Helmond*

Blom is the Strategic Advisor Mobility, City of Helmond, a small city in the southern part of the Netherlands. One third of all trips in Helmond are made by bicycle. Helmond is seeking mobility solutions other than only building new infrastructure. Based on this policy and their specific mobility challenges, Helmond has participated in several ITS projects. Helmond’s next steps for are (1) upscaling C-ITS services and (2) preparing for transition toward connected, automated driving.

Blom suggested that for smaller cities, automated and on-demand transit could increase service levels with lower costs. The initial plans for deploying automated shuttles include a connection between the train station and the Automotive Campus.

Blom emphasized the role of smaller cities as testing ground before moving to large cities. He argued that the city is good at doing things, such as closing roads for testing AV. He pointed out that ITS can only be part of a wider solution and described some of the challenges with involving CAVs, including the limited speed that makes these services compete with pedestrians and cyclists.

Blom noted that urban density plays a key role for planning services. European funding has also played a key role, especially for a small city such as Helmond, in testing innovative concepts. The challenge is to upscale pilot tests into normal services funded by regular financial sources.

Planning for the Transition Phase: How Milton Keynes will Facilitate CAV Introduction

Brian Matthews, *Milton Keynes*

Matthews is the Head of Transport Innovation, Milton Keynes Council (UK). Milton Keynes (MK) is a new city, founded in 1967. Its current population is approximately 265,000 and it is forecast to grow to 400,000. The projected population growth provides the context for applying innovative technology, especially automation, focused on safe, efficient, low carbon mobility. He noted that MK is the largest testing site for AVs in the UK through their involvement in “UK Autodrive,” a £20-million project that includes M1 saloon cars in MK and Coventry, a low-speed autonomous transport system (L-SATS) in MK, and 40 PODs to serve central MK.

Matthew reported that the long-term vision for the use of space is based on sharing, with some light separations at the beginning. A trade-off must be made between pedestrian density and possible POD speed. Public acceptance will be intensively researched during operation of the PODs. He noted that the approach in MK is unique as the city brought the cooperation for AV testing together. Key success factors include the collaboration between city–industry partners, national support, and keeping an eye on the business case.

David Murphy, *Waste Management Inc.*

Murphy is the Vice President of Corporate Venturing and New Products at Waste Management Inc. He discussed the unique challenges facing the waste collection industry in a fully automated environment, focusing on the “last 10 feet.”

Murphy noted that while automated waste collection shares many challenges with other areas of automation (e.g., no 3D mapping), it faces very specific additional challenges, including site access to private, fenced areas, locked bins, overfilled containers, litter lying around and other physical blockages, contaminated or hazardous waste, and humans sleeping in bins. The specific issues require solutions in automated waste collection.

PART 2: WHAT ARE CITIES’ EXPECTATIONS OF AUTOMATION?

Expected Impacts of Connected and Automated Driving in Cities

Scott Smith, *U.S. DOT Volpe Center*

Smith is a Senior Operations Research Analyst at the U.S. DOT Volpe National Transportation Systems Center. He discussed an impact assessment framework for AVs.

Smith noted that in order to determine the impact of AVs on cities, the following questions need to be answered. What do we mean by AV? What impacts do we care about? What are the key uncertainties? How will the uncertainties affect the impacts?

Smith reported that direct impacts can be measured in field operational tests, can be scaled up to the national level, can lead to indirect impacts, and can provide a foundation for assessing the indirect impacts that are of interest to society. Examples include impacts in the areas of safety, energy consumption, emissions, personal mobility, cost, and infrastructure needs.

Indirect impacts include network efficiency, travel behavior, public health, land use, and socioeconomic factors. Key concerns are the future of transit, highway capacity, the type of infrastructure needed in future, the development of demand and implications for revenue, and funding. Direct and indirect impacts are closely linked. The key areas of uncertainty are the future development of technology, user response to new vehicles and services, and directions of policy making.

Expected Impacts of Connected and Automated Driving in Cities

Martin Russ, *AustriaTech*

Russ is the Managing Director of AustriaTech, the federal agency for technological Measures of Austria, and also General Secretary of ITS Austria. He noted the need to support transport system and policy transition, and to safeguard desirable impacts.

Russ discussed that the context of cities and their use cases can be very different, and that cities should not be left alone in their uptake and decision-making processes by state and federal governments. Dialogue with national authorities, with industry, and on the international level are key success factors.

Russ noted that it is important for decision makers to position themselves in a learning cycle of mobility transformation, where automated driving is one aspect. Engaging in systematic learning is important. Austria is establishing different living labs around automated driving. He suggested that automation will produce desirable and undesirable impacts in cities, with which policy makers at all levels need to cope.

What Transport Authorities/MPOs Expect from Automation?

Perspectives from EU and U.S. Cities

Gert Blom, *POLIS (Belgium)*

Blom represented POLIS, an association of 70 mostly European cities and regions, and presented their preliminary views on AVs. In a situation where unrealistic expectations about the probable impact and availability of AVs are created, many cities want to be the first to have AVs 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.

Blom noted that 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 the most benefit to their city–region and develop policies accordingly. Cities need to explore urban planning and development,

specific automated services, safety of VRUs, travel behavior changes, and traffic management implications.

Blom reported that 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 AVs on urban and regional transport is needed (travel behavior, VRU interaction and safety, infrastructure implications, new transportation services, etc.); and
- EU and national policy on AV should give greater consideration to sustainable urban mobility policy.

Mollie Pelon, *National Association of City Transportation Officials (NACTO)*

Pelon is the Technology and City Transportation Program Manager at NACTO. She presented the views from her city members, which includes that streets now need to serve many goals. She noted that the private sector provides the new products, but the public sector needs to shape the outcome.

Pelon suggested that making AVs work for cities requires:

- Improving safety, which includes looking at limiting speed to 25 mph in the city (for all vehicles including AV);
- Sharing data to manage streets in real time (e.g., a third-party platform to share anonymous data);
- Expanding transit, with high ridership transit as a backbone, flexible services to connect point-to-point; and
- Democratizing the curb.

Modeling Connected Automated Vehicles in Urban Traffic Simulation Models: Expectations from U.S.–EU Research Cooperation

Jiaqi Ma, *Leidos*

Ma is the Transportation Project Manager and Research Scientist with Leidos, Inc., working at the FHWA Turner Fairbank Highway Research Center. He is leading an FHWA-funded project on the development of an AMS Framework for V2I and CV Environment. The objectives of the project include foundational framework for the development of AMS tool capability that includes CAVs, and to engage in small-scale V2I AMS development, using this framework.

A gap analysis has been undertaken and has identified the need for additional calibration of flow modelling (especially interaction between driverless and other vehicles), uncertainties on behavior side, and missing telecommunications aspects of V2V and V2I from existing traffic models. The main shortcoming is that current tools cannot predict the emergence of new modes and forms of mobility and can, therefore, not model the full implications of new mobility supply scenarios.

The next project phases include:

- Using existing datasets or design experiment to collect more data for model calibration;
- Selecting 3 to 5 sites for modeling deployment and testing (of selected CAV applications);
- Developing a CAV AMS toolbox; and
- Working with agencies to conduct case studies, focusing on early deployment opportunities (CACC, intersection approach and departure, and speed harmonization).

Siegfried Rupprecht, *CoEXist Project*

Rupprecht, is the Executive Director of Rupprecht Consult and coordinator of the CoEXist Project. CoEXist is a 3-year, collaborative research project, funded through the EU’s Horizon 2020 programme. It has been selected for the EU–U.S. twinning cooperation and will work closely with the FHWA-funded activities on developing an AMS framework, as presented by Jiaqi Ma.

The CoEXist AMS Framework will include the following:

- Simulation tools (developed by Renault, Vedecom, TASS International, and PTV): create a closed-loop connection between Renault & Vedecom CAV control logic with PreScan AV simulator and Vissim traffic flow simulator to extract behavioral parameters of CAV applications.
 - Modeling tools (PTV and University of Stuttgart): CAV-ready microscopic traffic model (PTV Vissim) and CAV-ready macroscopic transport model (PTV Vissim).
 - Analysis (VTI–Swedish Road Research Authority): impact assessment metrics for traffic performance, infrastructure space efficiency, and road safety for the CAV context (based on model results).
 - Demonstration of CoEXist AMS: eight use cases in four European road authorities (Gothenburg/Sweden, Helmond/The Netherlands, Stuttgart/Germany and Milton Keynes/U.K.) with different urban structures and traffic compositions.

Ma and Rupprecht presented the CAV AMS and CoEXist project twinning. The aim of the Research Project Twinning Initiative of the EC and the U.S. DOT is the “coordination of research activities in funded research projects of mutual interest, and the collaboration that occurs during the conduct of this research on the basis of mutual benefit.” It entails regular interaction, including face-to-face meetings, based on a twinning agreement.

The aims of cooperation of CoEXist and the FHWA funded CAV AMS activities are to:

- Define AMS tools that incorporate features of CAVs adequately;
- Apply AMS tools to several real-world use cases;
- Study CAV impacts (use cases); and
- Develop guidance for deployment.

Their strategic aims are to

- Coordinate the definition of a common representation of CAVs in traffic simulation models; and
- Help create more robust modeling products that produce compatible and more widely validated outputs (in traffic flow microsimulation and CAV impact assessment).

PART 3: DISCUSSION “ACTION PLANNING: WHAT CAN CITIES DO TO MAKE AUTOMATION WORK FOR THEM?”

The concluding panel discussion identified key elements of an urban automation policy agenda and how this agenda could be coordinated with industry plans. Session presenters served as panelists.

Observations from the audience and panelists included:

- Similar goals among the larger cities including safety, inclusion–access, and mobility;
- Concern in cities: a lot of OEM testing, but no partnerships;
- Interest in supporting walk, bike, transit;
- Equity concerns: AVs are not just for the wealthy;
- No automation without connectivity;
- Where should cities start, should they still invest in large buses and the like? Answer: Automation is a new topic for most cities, it needs joint efforts, and penetration of AVs is slow. Obtaining the ownership of stakeholders and involving citizens is important (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 very different (“social experiment” versus more technical approaches). Is there a right approach? Answer: Both approaches should coexist and need to learn from each other; and
- What should cities do? Answer: Work closely with OEMs while they are looking for new markets and are interested in demonstrations in cities; be clear about policy goals and create trust.

Suggested Action Items

Participants discussed what policy makers in cities should do to create an enabling policy framework for transport automation that also contributes to meeting key urban policy goals.

Basic “automation readiness” criteria identified included:

- Make sure you have clear, widely supported policy goals—and expected CAV contributions.
- Create a strong multistakeholder partnership (private–public, public–public, between departments, state–national support?).
- Get going. Follow a lightweight, incremental approach. Systematically build critical mass.
- Manage (complex/ contradictory) citizen expectations. Communicate, “It is innovation.”
- Keep an eye on the business case.

Implementing automation:

- Think about impact assessment “from day 1.”
- Identify clear performance measures for automated services/providers (local KPIs).
- Clarify expectations on users’ cross-brand experiences (or a uniform local brand?).
- Involve other municipal services (e.g., waste collection, street cleaning, snowplowing).
- Space management is a key future challenge (on-street/off-street).

The wider context of automation and innovation

- Ensure automation is part of an innovation cycle (incremental learning).
- Synchronize technology and policy transition: the new mobility paradigm in your city.
- Consider the wider transition landscape (MaaS, digital infrastructure, energy, etc.) and how supporting ecosystems can contribute (e.g., planning, labor relations, procurement).
- Engage in learning and exchange activities, including international dialogue.

APPENDIX U

Breakout Session 21: Connected and Automated Vehicles in Traffic Signal Systems

ORGANIZERS

Larry Head, *University of Arizona*; Henry Liu, *University of Michigan*; and Young-Jun Moon, *The Korea Transport Institute*

REPORTERS

Henry Liu, *University of Michigan*; and Young-Jun Moon, *The Korea Transport Institute*

SESSION FOCUS

There were nine presentations and follow-up discussion in this session. The goal of this two-part breakout session was to explore opportunities for new approaches to the control of signalized intersections, or more broadly controlled junctions, for CAV. This session explored the role of infrastructure and the vehicle in decision-making and control decisions and how vehicles and the infrastructure can cooperate toward safer and more efficient operation. Further research opportunities and issues regarding traffic control with CAVs were discussed during the session.

PowerPoints of most of the presentations are available on the AUVSI website at <http://www.automatedvehiclessymposium.org/avs2017/program/proceedings>.

SESSION SUMMARY

From Partially CV to Fully CAV Environment

Participants discussed that while the penetration rate of CAV will reach to 100%, there will be a transition to get to that level. At the beginning, there will be an increase in terms of connectivity, because there is already connectivity involved in the vehicles using cellular data in smartphones. AVs will appear gradually with different levels of automation. The penetration rate of lower-level AVs will be increased first and eventually the higher-level AVs (e.g., Level 5) will be dominant. One question is how to use the current level of connectivity to improve traffic signal systems? The answer to this question helps to create incentives for agencies to invest in this technology. Additionally, the answer can be elaborated in different dimensions such as low versus high demand level, single intersection versus corridor, and single mode of users versus multimode users, such as including pedestrians and bicyclists. The other important question is the required infrastructure changes to accommodate the CAV technology (e.g., dynamic lane grouping). This change needs to be considered in terms of both hardware and software necessities in deploying CAV technology. For example, the traffic controllers' firmware should

be changed to adopt the technology. The controllers need to be replaced with faster and more powerful processors with higher interoperability.

Levels of Intelligence in Traffic Signal Systems under CAV Environment

Participants discussed that traffic signal control systems may have different levels of intelligence. The level of intelligence at intersections may be dependent on the CAV penetration rate. In the areas with low penetration rates, time-of-day coordinated actuated signal control system may be useful. In other areas where the infrastructure is not ready for CAV technology, some traditional adaptive systems (e.g., SCOOT) may remain in operation. However, as the CAV penetration rate increases and the infrastructure catches up with the technology, a more advanced adaptive control can be substituted in order to utilize the data from CAVs and to provide smarter control decisions. If the penetration rate is high enough, it may be possible to have detector-free dynamic coordinated/adaptive signal control systems. Therefore, the intelligence level of intersections can grow as the intelligence level of vehicles increases.

Emerging Objective Functions in Traffic Systems

The objective function of the traffic control optimization models may be changed with emerging CAV technology. A vast range of objectives such as sustainability, energy, reliability, or comfortability may have more importance than conventional objectives, such as delay. For example, a person who is watching a football game in his CAV may want to get home slower so that he can watch the whole game without interruption. There may be models that consider multi-objectives simultaneously depending on traffic agency-passenger preferences.

Other Sources of Data Rather than CAV Data

One of the participants discussed his experience in the Netherlands, noting that location-based data from probe vehicles can be useful to replace some of the conventional loop detectors and can be helpful to provide smarter traffic control decisions. Even 10% or 15% of vehicle data from Google, Waze, or TomTom can make a reasonable difference. Therefore, it is not necessary to have CV data for better traffic control. With the emerging of the shared-mobility companies, another source of data has been introduced. If the data from shares-mobility companies can be shared with the research community, observability of traffic increases. Increases in traffic observability create opportunities in smarter traffic controllability. According to a study that has been conducted with Didi data (Chinese Uber), even with knowing the trajectory of only 3% of the vehicles, a much better traffic control can be achieved. The parameters of the traffic signals in the case studies in the experiment, were optimized every week based on the collected data. This study shows the importance of mobile-based sensors from connected vehicles.

CAV Technology Redefines the Capacity Level

Participants discussed that the CAV technology can increase the number of vehicles on arterials that can result in a more congested situation. As the capacity level is reached, there will not be much room for any signal optimization model to lower congestion. This negative impact may reduce the benefit of CAV technology in improving the current traffic signal systems. It should

be noted however, that the theoretical analysis of capacity will be changed by increasing the number of CAVs. The CAV technology will allow more cars to move. This extra capacity is because of shorter headway between CAVs. Therefore, CAV increases the capacity levels of arterials.

Other Concerns Related to CAV in Traffic Signal Systems

The following concerns were also echoed at the end of the discussion in this session.

- In the current practice of traffic engineering, there is no uniform standard of evaluation for traffic signals. Different agencies have different criteria to measure the efficiency of their traffic systems. So understanding the objectives of traffic agencies is very important in defining the required benefits of CAV.
- CAV technology may involve many disciplines. Therefore, a multidisciplinary approach or discussion between traffic engineers and experts from other fields may be valuable for future studies in traffic signal systems.
- Pedestrians are not usually considered when studying signal control under the CAV environment. Pedestrians and bicyclists should be included in future traffic signal studies in the CAV environment.

Suggested Action Items

- Participants discussed the intelligence level of traffic control and defining an intelligence level of traffic control, similar to vehicle automation level defined by SAE. For example:

- Level 0: Fixed-time control (time-of-day);
- Level 1: Existing adaptive control system (e.g., SCOOT); and
- Level 2: Detector free signal control (smarter coordinator at the intersection).

More research to develop this concept was suggested by participants. Additionally, related to the connectivity and automation diagram, participants identified needed research on intersection intelligence-level changes with levels of connectivity and automation.

- Participants discussed the need for research associated with performance measures, noting that the objective function of traffic control may change with AVs. A current performance measure is intersection delay for vehicles. This measure may need to change to person delay. Possible new objectives and performance measures may focus on sustainability, energy, and risk minimization. Further, participants suggested that research on objectives and performance measures, which may be needed during the transition period, would be beneficial.

- Participants discussed that CAVs will provide continuous data. Research is needed to examine how trajectory data will replace conventional detection and if loop detectors will disappear. Research on how navigation data from Google, TomTom, and other providers can be used in this setting was also identified as needed by participants.

- Participants supported encouraging shared mobility companies to share their data with the research community.

- Participants discussed that controllability should increase over time with changes to higher automation levels. Based on the Didi experience, it appears that using only trajectory data can result in the generation of better signal timing plans. Participants suggested that examining

the Didi experience, including the frequency of signal retiming and closed loop control instead of open loop control, would be beneficial.

- Another research topic identified by participants was a theoretical analysis of capacity increases with the increase in automation level. Traditional traffic control has fixed capacity with a focus on how to better allocate the capacity and remove inefficiency. Traffic control with CAVs should increase capacity, allowing more cars to move through an intersection. The research should include pedestrians who are usually not considered when studying signal control with CAVs, and the potential for increased capacity to increase demand, which may result in more congestion.

- Other research topics identified by participants included examining customer acceptance of CAVs, the impact of vehicle technologies on CAVs, and centralized versus decentralized traffic control algorithms.

APPENDIX V

Breakout Session 22: **Legal and Policy Approaches** *Finding the Right Balance on Legislating for Automated Vehicles*

ORGANIZERS

Carl Andersen, *Federal Highway Administration*; Amitai Bin-Nun, *Securing America's Future Energy*; Baruch Feigenbaum, *Reason Foundation*; Dov Friedman, *Securing America's Future Energy*; Ginger Goodin, *Texas A&M Transportation Institute*; Anita Kim, *U.S. DOT Volpe Center*; Shawn Kimmel, *Booz Allen Hamilton*; Nira Pandya, *UC Berkeley Law*; Ellen Partridge, *Environmental Law Policy Center*; Karlyn Stanley, *RAND*; Tammy Trimble, *VTTI*; and Bryant Walker Smith, *University of South Carolina*

REPORTER

Tammy Trimble, *VTTI*

SESSION FOCUS

States are taking different approaches toward developing and enacting legislation specific to AVs. While some states have defined clear and explicit rules for testing and operating AVs on public roads, other states have adopted a more hands-off approach and avoided legislating in this area. Last year, the U.S. DOT released a model state policy to guide state and local agencies. In addition, several associations and organizations have begun their own initiatives on developing model state legislation regarding AVs. The goal of this session was to bring together the various groups working on, or influencing, the development of legislation and to discuss how to develop a framework and potentially desirable elements of effective legislation for AVs.

The PowerPoints of most of the presentations are available on the AUVSI website.

SESSION SUMMARY

The session consisted of two panels designed to set the stage in regard to current organizational and legislative approaches to the development and enactment of AV-specific legislation. Interactive discussions followed each panel. The afternoon concluded with small group interactive breakout discussions on future policy-related needs, a discussion of the major themes covered during the session, and suggested action items.

Panel 1: “Speed Dating”—The Organizational Perspective

Bryant Walker Smith, *moderator*

Because so much work has been done in the past year, this session presented a quick overview of who is doing what through a “speed-dating” round. Representatives from nine organizations gave short presentations on what their organization is doing (e.g., developing principles, drafting legislative language, convening), and their key policy wish from federal, state, or local government, or standards development organizations. More information on the presentation details may be found in the available PowerPoint slides.

Following the brief presentations, each presenter joined a separate table and engaged in conversations on the topics. Presenters rotated to other tables for new conversation every 5-10 minutes.

The following individuals provided brief presentations.

- James Fackler, *Vice Chair, American Association of Motor Vehicle Administrator’s (AAMVA’s) Automated Vehicles Best Practices Working Group*;
- Lindsay Beaver, *Legislative Counsel, Uniform Law Commission (ULC) AV project*;
- David Kidd, *Senior Research Scientist, IIHS*;
- Mollie Pelon, *NACTO*;
- Russ Martin, *Director of Government Relations, Governors Highway Safety Association (GHSA)*;
- Art Guzzetti, *American Public Transportation Association (APTA)*;
- Mark Norman, *Director of Development and Strategic Initiatives, TRB*;
- Anne Marie Lewis, *Director of Safety & Technology, Auto Alliance*; and
- Jack Pokrzywa, *Director of Global Ground Vehicle Standards, SAE International*.

The following resources were noted during the discussion.

- AAMVA’s Autonomous Vehicles Best Practices Working Group.
- ULC’s HAV project.
- IIHS’s Automation and Crash Avoidance.
- NACTO City Data Sharing Principles: Integrating New Technologies into City Streets.
- NACTO Policy Statement on Automated Vehicles.
- GHSA AV efforts which includes the Autonomous Vehicles Meet Human Drivers: Traffic Safety Issues for States.
- APTA’s Shared Mobility and the Transformation of Public Transport.
- SAE’s Ground Vehicle Standards.

Panel Two: Developing Legislation: A Panel of State Elected Officials

Shailen Bhatt, *Director, Colorado DOT, moderator*

This panel included representatives from four states that have been involved in developing AV legislation. The panel discussed their perspectives and challenges with crafting legislation, and offered insight into their state's experience.

Panelists included

- Senator Jeff Brandes, *Florida State Senate, Chair, Appropriations Subcommittee on Transportation*;
- Representative Jeff Bridges, *Colorado General Assembly*;
- Senator Jon Lundberg, *Tennessee State Senate, Vice Chair, Government Operations Committee*; and
- California State Assembly member Susan Bonilla (retired), *CA Director of Council for a Strong America*.

PANELS ONE AND TWO DISCUSSION SUMMARY

Prior to moving to the interactive breakout activity, a summary of key ideas from the two panels were presented. These ideas include the following.

- Participants identified several questions for consideration. What are the desired outcomes? What are we trying to accomplish? What is needed to get to the scenario outcomes?
- Participants discussed the following data needs.
 - Data sharing and policies should ensure that data is collected in a structured, systematic way.
 - There may be expectations of obtaining more data than what is available or needed to regulate.
- Participants discussed what are regulators trying to accomplish?
 - There is a need for high-level system management. There are many associated moving parts with AV policy development and understanding what is needed at the federal and state levels is a first step.
 - Need to determine what legislation is needed and to clarify responsibilities between the federal government and state governments.
 - Need to understand that there is a blurred line between testing and deployment.
 - Need to be honest and realistic in the approaches used and recognize that all issues cannot be solved at once.
 - May need to develop use cases/scenarios and outcomes.
- Participants discussed infrastructure needs.
 - How will these needs be paid for? Who will pay?
 - Differences between rural and urban needs must be recognized.
- Participants discussed how to address other challenges that may arise.
 - Examples of these issues included zombie cars, security issues, land use issues, and environmental concerns.

- Each of these issues creates its own set of challenges that will have to be addressed, which will require an understanding of the problems and opportunities created by each issue.

INTERACTIVE BREAKOUT: HARMONIZING AV LEGISLATION

The final portion of the session was dedicated to interactive breakout discussions on developing uniform legislation regarding AVs. This discussion focused on key topics, such as local preemption, state regulatory rules, and operational challenges. The session drew upon the expertise from both the panels and the discussion to highlight the benefits and limitations of various elements of AV legislation.

The discussion was guided through the following of questions.

1. Preemption. Motor vehicle laws are made at the state level but many cities set their own transportation policy. Should states be able to stop local counties and cities from making their own AV laws? Are all issues not decided at the state level open to local interpretation or should the states make all the laws?
2. Insurance–liability. What is the appropriate amount of insurance coverage to have for a self-driving vehicle? Should the individual, the automaker, or the fleet owner (shared vehicles) be responsible for insurance? Should AVs be charged a lower or higher insurance rate than human-driven vehicles?
3. Explicit legislation. Should AV legislation be heavy handed or apply a light touch? Some states have developed specific testing and licensing requirements (driver in car, special license plate, specific level of insurance, etc.) for AVs, while others have provided minimum requirements mostly found in existing legislation. Is one approach better? Is it a combination?
4. Safety. Some experts believe that since AVs are expected to significantly decrease vehicle accidents and fatalities, society should place AVs on the road as quickly as possible. Others argue that the Tesla crash shows that automakers will rush to put untested, unsafe vehicles on the road and that the government must take steps to protect consumers today. Is there one right answer? Is it a combination of these two options?
5. Implementation. Legislators make laws but government agencies, engineers, and planners will be responsible for implementing policies. How should these entities work together? Is there some type of formal feedback loop or communication? How should implementers respond to a sudden change in technology? What happens when state and local policymakers disagree on implementation methods?

SUMMARY OF KEY THEMES

The following key themes emerging from the participant discussion were summarized.

- Participants noted that AVs are a positive development for safety, mobility, and convenience.

- Participants suggested that data should be collected in a structured, systematic manner. Additionally, there is a need for more data-driven research results to drive decision making.
- Participants noted a need for high-level system management, a new taxonomy of roads (urban–rural), and scenario planning for options.
- Participants suggested that legislation should serve as building blocks. To avoid overregulation (which may stifle innovation) and/or layers of obsolete legislation, legislative efforts in the AV area should be evolutionary and incremental in nature. Recognizing that there may be periods of disruption as technology advances was also noted as important.
 - Consider including sunset provisions in legislation.
 - Consider the desired outcomes and focus on maximizing options for the future.
 - An incremental approach would allow time to build citizen trust so that when crashes or incidents occur they will understand that crashes can happen even with the best technologies and safety processes.
 - It was suggested that mindsets will evolve. An example provided by participants was that elevators initially had operators because the public could not be trusted to operate them. It was noted that fatalities occurred in early days of aviation testing, yet that did not stop the advancement of the aviation industry.
- Participants suggested that overregulation should be avoided as technology is advancing faster than legislative–policy planning activities.
 - Policy decisions on a wide range of topics (e.g., transit, infrastructure planning, land use, environmental impact) should be made with AV in mind.
 - While overlapping, shared mobility, electrification, and automation each bring unique challenges and opportunities to be considered.
- Participants discussed the need to balance the urge to foster innovation and the development of AVs with the responsibility to serve the public, protect their interests, and keep them safe.
 - When thinking about introducing AVs, mobility, equity, and accessibility to transit for all populations (e.g., economically disadvantaged, disabled, and aging populations) should be considered.
 - Consideration should be given to how the workforce will be affected in the future and ways to make needed transitions.
- Participants discussed the importance of relationships and personal connections among stakeholders (e.g., policy makers, administrators, legislators, law enforcement, technology developers and other experts, and the public). These relationships should not be underestimated as they will help to move policies forward.
 - Look for ways to bring stakeholders together to talk about the issues (e.g., an AV caucus or task force).
 - Law enforcement personnel should be engaged early in the process of developing AV solutions.
 - Policymakers should be encouraged to consider the experience and opinion of administrators and others who have the expertise in this area. Conversely, administrators (as well as other stakeholders) need to engage with, and provide information to, policymakers and the public on the issues.

- Participants noted that the issues related to interoperability (e.g., with commercial vehicle operations) will need to be addressed at some point and that federal activity may be necessary.

SUGGESTED ACTION ITEMS

- Participants noted the continuing need to provide better education for policymakers and the public. It was further noted that this is the third year for a policy breakout session, and that the need for better education has been a priority each year. Participants discussed that targeting resources to develop enhanced information and conduct outreach efforts would be beneficial.
 - Another follow-up activity suggested by participants was providing an integrated process for policymakers to work with each other across government levels and through public-private working groups. It was noted that each group is studying issues individually with very little coordination across efforts.
 - Participants suggested the need to look to the future, but focus on the near term. It was noted that there is a tendency to focus on SAE Level 5 AVs, but that intermediate levels of AVs offer advantages as well.

APPENDIX W

Breakout Session 23: Connected Automated Vehicle Early Deployment Alternatives

ORGANIZERS

Dale Thompson, *FHWA, Operations Research and Development*; Xiaoyun Lu, *University of California, Berkeley*; Jiaqi Ma, *Leidos*; Taylor Lochrane, *FHWA, Operations Research and Development*; and Edward Leslie, *Leidos*.

REPORTERS

Dale Thompson, *FHWA, Operations Research and Development*; and Edward Leslie, *Leidos*.

SESSION FOCUS

The objective of this breakout session was to identify research topics that need to be addressed to overcome the challenges and to take advantage of the opportunities from using connected automation to improve transportation operations. Breakout sessions in previous AVS events have focused on Level 1 automation, primarily connected longitudinal control, by means of V2V or V2I. This session introduced two promising applications – CACC for freeway operations and eco-approach and departure (EAD) to signalized intersections. Ongoing research by government and industry toward developing these applications were discussed. The test facilities and test progress for early CACC prototypes were described. The results of simulation studies of CACC for application to realistic traffic scenarios was presented. Research gaps were identified for use in developing possible research needs problem statements for consideration by TRB committees.

PowerPoints of most of the presentations are available on the AUVSI website at <http://www.automatedvehiclessymposium.org/avs2017/program/proceedings>.

SESSION SUMMARY

FHWA Connected Automation Research Program

Dale Thompson, *FHWA, Operations Research and Development, presenter*

- Who we are: FHWA Saxton Transportation Operations Laboratory, Turner–Fairbank Highway Research Center
 - Nation’s premier federal surface transportation research facility.
 - Home to eminent transportation scholars and state-of-the-art research vehicle fleet.
 - Conduct cooperative automation research and provide infrastructure leadership.
 - Collaboration with federal and industry partners.

- Three unique laboratories:
 - Data Acquisition Lab.
 - Urban Test Environment.
 - Modeling and Simulation Testbed.
- Road–vehicle automation research focus:
 - Light vehicle connected and automated fleet.
 - CACC applications.
 - Light vehicle and truck platooning.
 - Signalized intersection approach and departure applications.
 - Automated traffic flow optimization.
 - Lane change, merge, and weaving operations concept development.
- Connected vehicle research focus:
 - V2I–I2V communications.
 - V2V communications.
 - Hardware interoperability testing.
 - Software applications and research platform.
- AV deployments:
 - L1/L2 AV systems being tested for early deployment.
 - L4/L5 AV systems in simultaneous testing for early deployment.
 - Some AVs will not have connectivity or cooperative communications.
- Operational impact:
 - AVs should work effectively and optimally within the transportation system.
 - AVs have the potential to extend mobility and employment benefits.
 - Connectivity can provide additional system benefits and AV efficiencies.
- Current FHWA research:
 - L1/L2 cooperative automation vehicle characteristics.
 - CACC platooning and cooperative automation algorithms.
 - Development and evaluation test plans.
 - Hardware interoperability testing.
 - Demonstrations.
- Signalized intersection approach and departure research:
 - V2I–I2V communications.
 - Test examines the environmental and fuel economy benefits of partial automation.
 - Result: 22% fuel economy improvement with partial automation versus 7% with manual driving.
 - Time saved from reducing start-up loss.
 - Imagine how much time and fuel can be saved across 300,000 signalized intersections nationwide.
 - FHWA is doing more to bring technology such as this to the road system.
- Speed harmonization and traffic flow optimization:
 - Using V2I–I2V communications.
 - Almost doubles the lane capacity.
 - Reduced headways (0.6 s).
 - Reduced need for building additional infrastructure across the country.
 - New roads cost ~ \$2 million/mi.
- Truck platooning:

- Seamless freight transportation powers the economic engine.
- Goods worth more than \$49 billion each day move on the road network.
- Growing demand—17 billion tons (2012) to 25.3 billion tons (2045).
- Reduced drag improves fuel efficiency.
- Faster responses to hard braking by preceding—lead vehicle.
- Lane change, merge, and weave proof of concept:
 - V2I–I2V communications.
 - V2V communications.
 - Hardware interoperability testing.
 - Software applications and research platform.
- Light vehicle platoon stream performance:
 - Understand the stability of platooning and interaction at highway interchanges involving merging, diverging, and lane change to address bottlenecks.
 - Investigate the interaction between light and heavy vehicle platoons as truck platooning becomes more common on major corridors.
 - Develop performance characteristics for platooning with different vehicles types (i.e., car, truck, SUV) to support modeling and simulation.
 - Effects of platooning in traffic and role of infrastructure to reduce TT and increase throughput.
- Data acquisition:
 - Approximately 60 GB data.
 - Approximately 100 GB video.
 - Intent is to share research results data.
 - Comprehensive test plans.
- Research and testing partners:
 - Aberdeen Test Center, U.S. Army.
 - Federal Law Enforcement Training Center, U.S. Department of Homeland Security.
 - Virginia DOT Northern Virginia Testbed.

Cooperative Automation and Cooperative Adaptive Cruise Control Integrated Prototype Project

Edward Leslie, *Leidos, presenter*

Project Objective

Assess AV operational characteristics using CACC and other applications to determine system-wide operational impact.

- Project partners and contributors:
 - TORC Robotics: truck hardware mods, software development.
 - UC Berkeley PATH: platooning algorithm, heavy truck dynamics.
 - UC Riverside: GlidePath algorithm.
 - Auburn University: heavy truck platooning.
- Major components:

- Connected Automation Research for Modeling and Analysis (CARMA) platform.
- Algorithm rehosting and refinement:
 - Platooning.
 - Intersection approach and departure.
 - Lane change and merge.
 - Speed harmonization.
- GlidePath enhancement.
- Integrated highway priority prototype.
- Connected truck prototype.
- CARMA Platform Development
 - Develop the Evolutionary Framework Vision document.
 - Define requirements.
 - Develop architecture specification.
 - Detailed design specifications (hardware and software).
- CARMA Implementation
 - Iterative (agile) software development life cycle.
 - Research vehicle reusable–portable control system structure.
 - Deploy CARMA platform on the vehicle fleet.
 - Interfaces with DSRC onboard units (OBUs), GPS, data acquisition systems, and portable device user interface.
 - Modular transportation strategies and applications interfaces.
- System testing and prototype demonstration:
 - Early verification test.
 - Iterative stages of evolutionary testing.
 - Verification that functionality meets stated requirements.
 - Comprehensive (validation) test.
 - All test phases will involve defect fix and re-test as needed.
- Algorithm development–evolutionary approach:
 - EAD (GlidePath):
 - Port of advanced algorithm to be developed under this project to the new architecture.
 - Platooning:
 - Update the CACC algorithm proven under earlier task order.
 - Lane change and merge:
 - Port the application to the new architecture.
 - Speed harmonization:
 - Second-generation capability developed under an earlier task, but not yet fully tested.
- Integrated Highway Priority Prototype Test and Demonstration:
 - Control software development and integration into new CARMA platform:
 - Integrates multiple freeway algorithms: platooning, lane change/merge, speed harmonization.
 - Will use algorithms designed under a separate task.
 - Basic simulation before deploying to vehicles.
 - Validation testing support at Aberdeen Test Center (ATC).
- Connected truck prototype demonstration:

- Mixed platoon—heavy truck with passenger cars.
- Control software enhancement and integration:
 - Implement CARMA platform hardware (PC, CAN interface, data acquisition, etc.).
 - Develop basic longitudinal control for heavy truck.
 - Adapt the platooning algorithm to truck complexities.
 - Preliminary functional testing at VTTI test track.
- Validation testing support at ATC.
- Project milestones
 - Vehicle to be built and delivered with beta Prototype 1 in November 2017.
 - Testing at ATC to begin in December 2017 and run through September 2018.
 - Integrated Highway Prototype to be ready for demonstration on public road June–July 2018.
 - Passenger car platooning with truck testing at ATC to begin summer 2018.

Performance Analysis of CACC Impact on Freeway Traffic Through Simulation

Xiao-Yun Lu, *PATH Berkeley, presenter*

- Traffic modeling in simulation, baseline:
 - Simulation platform: Aimsun.
 - Freeway corridor SR-99 NB modeling with field data:
 - Elk Grove → Intersection with SR-50.
 - 16 on-ramps.
 - 11 off-ramps.
 - Metering included.
 - Five-minute onramp and most upstream mainline flow data of Caltrans Performance Measurement System with some clean-ups and modifications used for demand.
- Traffic modeling in simulation, baseline:
 - Model parameters determination:
 - Reaction time: 0.8 s.
 - Maximum acceleration–deceleration: $2 \text{ m/s}^2 / -4 \text{ m/s}^2$.
 - Mean desired headway: 1.4 s.
 - Lane changing anticipatory distance: 1.5 km.
 - Special treatments:
 - Most upstream bottleneck: reaction time 1.0 s.
 - Most downstream bottleneck: reaction time 0.4 s.
 - Lane changing anticipatory distance 0.6 km.
 - CACC driver behavior modeling:
 - Passenger car: based on four CACC car test data.
 - Driving mode: CC, ACC, and CACC.
- Managed lane impact for CACC operation
 - Without discretionary lane change (DLC): can increase the capacity at higher CACC deployment, little effect on merging (encouraging platoon keeping).
 - With DLC: little impact on the capacity at merge since it cannot reduce the disturbances by the ramp mandatory lane change.

- Managed lane for CACC vehicles: Changing access strategy may reduce the number of mode switching and can increase the capacity at lower CACC deployment.
- On-ramp demand increase:
 - On-ramp traffic input: 300, 600, 900, 1,200, and 1,500 vehicles per hour (VPH).
 - CACC: 40%, 60% and 80%.
 - Number of managed lanes: one managed lane for 40% CACC case; one and two managed lanes for 60% CACC case; and one, two, and three managed lanes for 80% CACC case.
 - Managed lane increases the capacity at 40% and 60% CACC cases, especially when the ramp input is larger than 600 vph.
 - It has little effect at 80% CACC case.
- System performance increase with CACC managed lane, DLC, and vehicle awareness device (VAD) implementation
 - Over 20% VTT reduction and 20% speed increase at 60%, 80%, and 100% CACC deployment.
 - At 40% CACC, most severe bottleneck is completely removed.
 - CACC improves corridor traffic.
- Conclusion
 - CACC string operation with public traffic on freeway could significantly improve overall traffic performance by increasing mainline capacity if the following are adopted:
 - Managed lanes: Aggregating CACC vehicles in certain lanes such as HOV lanes.
 - Restricting discretionary lane changes: Keeping CACC strings.
 - With VAD deployment: Act as leader vehicle of a CACC string.
 - It has some but not significant improvement in merging area—needs more research.

Signalized Intersection Approach and Departure Research Results

Jiaqi Ma, *Leidos, presenter*

- Objective:
 - Smooth flow through intersections provides economic, mobility, and safety benefits.
 - Vehicle receives signal control information and determines optimum speed through intersection.
 - Optimize traffic metrics (TT, fuel and emissions, safety) through various trajectories.
- Components:
 - V2I communications between signal controller (transmitting SPaT/MAP) and vehicle via RSU.
 - Vehicle OBUs transmit–receive basic safety messages (BSM).
 - Vehicle equipped with the EAD at signalized intersection application (GlidePath).
- GlidePath application

- Vehicles optimize their own trajectories based on SPaT/MAP data, vehicle BSM data, and the GlidePath algorithm.
- Five-phased implementation: accelerating, cruising, decelerating, idling, and accelerating.
- Simulation scenario and results:
 - Variable market penetration: 10%, 30%, 50%, and 100%.
 - Light traffic (100 vphpl) and heavy traffic (700 vplph) scenarios.
 - Manual driver–vehicle interface provided a 7% fuel improvement.
 - Semi-AV driving provided 22% fuel improvement.
 - Minimizing signal controller lag is critical to accuracy.
 - Precise positioning of intersection stop bar is important.
- Next step: Hardware in the Loop
 - CAV with CACC capability and GlidePath algorithm.
 - Real intersection (National Transportation Communications for Intelligent Transportation System Protocol compatible) with RSU transmitting SPaT/MAP.
 - V2I hub prototype for DSRC message transmission–receipt and interface to actual and simulated environments.
 - Software simulation environment provides emulated vehicles traveling with actual CAV on testbed using VISSIM.
 - OBU GlidePath application calculates actual vehicle position along with simulated vehicles in stream to optimize approach and departure.

SUMMARY OF RESEARCH NEEDS

Cooperative Adaptive Cruise Control—Light Vehicle Platooning (Longitudinal Control)

- Proven concept feasibility.
- Single OEM platform.
- Recommended next steps: platoon stability, performance character, light–heavy vehicle stream, and infrastructure.

Signalized Intersection Approach and Departure: GlidePath

- Single vehicle, single intersection.
- 7% fuel improvement manually, 22% fuel savings.
- Next steps: two vehicles, two intersections.

Speed Harmonization

- Strategy: modeling streams of vehicles receiving speed control recommendations from TMC.
- Benefits: Reduced congestion and potential to double vehicle capacity.
- Next steps: assess system-wide benefits from CAV at various deployment scales.

SUGGESTED ACTION ITEMS

- Participants discussed needed research to begin to address real-world deployment issues.
- Research topics and next steps with CACC and light vehicle platooning (longitudinal control) identified by participants included examining ingress–egress merging, infrastructure impact, and premature damage. Other topics to examine in the research were the optimum size of platoons, gaps and headways, optimum vehicle performance criteria to engage in platooning, and handshakes between vehicles. Examining the potential for the early transition using managed lanes or dedicated lanes, and exploring lane change issues and visibility limitations of the lead vehicle were also suggested.
- Participants identified additional research on the signalized intersection approach and departure—GlidePath—project. Topics included examining mixed traffic impacts, connected and non-connected vehicles in a traffic stream, and vehicle performance characteristic algorithms for each vehicle.
- Possible research needs associated with speed harmonization identified by participants were exploring methods to obtain operating agency engagement early in field testing and analyzing benefits that justify investments.
- Cybersecurity risks also surfaced a research topic during the discussion. Participants suggested that examining infrastructure vulnerability and vulnerable vectors into vehicles as messages and requests go to vehicles from the TMC.

APPENDIX X

Breakout Session 24: Automated Vehicles for People with Disabilities

ORGANIZERS

Mohammed Yousuf, *U.S. DOT*; Sudharson Sundararajan, *Booz Allen Hamilton*; Jeff Gerlach, *Securing America's Future Energy*; Murat Omay, *FTA*; Aaron Steinfeld, *CMU*; and Corey Harper, *CMU*

REPORTERS

Sudharson Sundararajan, *Booz Allen Hamilton*; and Justin Owens, *VTTI*

SESSION FOCUS

This session focused on creating an awareness of the transportation needs and challenges faced by individuals with disabilities. The emphasis was on how embracing universal design principles in developing the AV technologies can make a difference in addressing the needs of all users equitably by enabling standards harmonization, data needs, and partnerships, as well as addressing policy barriers and technology challenges. The interactive session included short presentations and discussion questions to obtain feedback from participants to inform the U.S. DOT ATTRI and to help to develop research topics for the initiative's next phases.

SESSION SUMMARY

In 2010, the U.S. Census reported that approximately 56.7 million people in the United States had some type of disability. Inadequate or lack of 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, and attending social events. The U.S. DOT's ATTRI 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, AI, object detection, and navigation. These technologies are enabled by established wireless communications that connect travelers and their mobile devices, vehicles, and roadside infrastructure to create a linked transportation system that provides mobility options and allows seamless travel for everyone.

AVs and other complementary technologies have the potential to support ATTRI's objectives by introducing many transformational changes into the lives of people with disabilities. During the development stages of AV technologies undertaken by public- and

private-sector organizations, it is important to explore pathways to ensure that those new technologies are accessible and are 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, inclusive information and communications technology, institutional and policy barriers, interoperability, and standards harmonization.

The session was organized around two panels featuring short presentations. Questions were used after each speaker to facilitate participant discussion.

The first panel addressed design-related AV topics, including user needs and challenges, universal design principles for AVs, data needs, and institutional and policy barriers.

Aaron Steinfeld, CMU, discussed the needs and challenges that individuals with disabilities may face in using AVs. He described some of the difficulties encountered with using paratransit and the potential for AVs to reduce or eliminate these concerns. He noted the need for accessible interfaces within vehicles. He also noted the following elements:

- The ice cream test considers if a person could decide to go get ice cream at 10:00 p.m.?
- The disability community is heterogeneous and includes many people with many distinct needs.
- It is important to consider the interaction of AVs with people of all abilities.
- Navigation systems show the optimal route for a typical traveler, but are not designed to show the optimal route for people with disabilities and older adults who have different needs.

Edward Steinfeld, University of Buffalo, discussed universal design, including access and egress, and a universal interface system.

- He noted that the needs of the disabled community were similar to ours and that we should not design for disability, but for the needs of all.
- He stressed that the needs and challenges for each disability type is different and that AV design should consider integrating solutions to address those different needs and challenges.
- He noted the importance of considering the built environment. For example, steep slopes pose a major problem for individuals using wheelchairs.

Anat Caspi, University of Washington, described data needs and recent research examining sidewalks (<https://www.accessmap.io/>).

- He noted the importance of data formats and standardization (performance and outcome related) when considering information/data-based universal design. He also noted the importance of interoperability, interface/system integration, and navigation and mapping.
- He discussed the challenge of developing standards that are performance and outcome related. He noted that harmonized standards enable multiple industries to come together to provide a service.
- He discussed the potential of automated wheelchairs.
- He suggested the need for a conceptual framework to inventory, analyze, and develop requirements to address the varied needs and challenges of different disabilities.

Shawn Kimmel, Booz Allen Hamilton, discussed institutional and policy barriers, including the variety of state regulations and barriers to AV licensure.

- He noted that there are several policy and regulatory barriers that affect services, including paratransit service reservation within 24 h and service provision within a 2-h window.
- He described fully automated shuttles including Olli.
- He discussed ways to enhance disability needs awareness and universal design methodology.
- He highlighted the need for increased funding for infrastructure, data collection, technology, and other items.

The second panel focused on public policy and infrastructure-related topics, including institutional and policy barriers, other VRUs, infrastructure needs, and public–private partnerships.

Colleen Casey, Toyota, spoke on the importance of standards.

- She noted that the OEM perspective is to provide mobility solutions that have social impacts, including addressing the needs of the disabled community. She said that approximately 45% of people with disabilities do not have access to a passenger vehicle.
- She noted that standards are emerging across countries and that harmonization aims to minimize technical differences.

Justin Owens, VTTI, described human factors challenges and opportunities with the interaction of AVs and pedestrians with disabilities.

- He noted that pedestrians face challenges while interacting with vehicular traffic. Bidirectional communication with AVs is important, especially during the transition phase where AVs and non-AVs are in the traffic mix. He suggested that the fleet will be mixed for the next few decades.
- He noted that AVs may be able to provide numerous benefits for individuals with disabilities, including improving mobility, providing better detection, providing adaptable street crossing time, and other enhancements.
- He stressed the importance of bidirectional communication. He noted that the current challenge may be improved with connectivity and advanced technology. He further noted that while connectivity has benefits, it cannot be assumed that all pedestrians will be connected. He discussed onboarding and off boarding concerns, noting that everyone is a pedestrian at some point in their trip.
- He presented a demonstration of the VTTI pedestrian simulator.

Robbie Diamond, Securing America's Future Energy, discussed infrastructure issues.

- He noted that in developing AV design criteria for the target populations, including people/veterans with disabilities, and older adults, it is also critical to consider the interaction with the surrounding built environment. He stressed that without experience it is difficult to understand the real challenges people with disabilities face with insufficient infrastructure. He raised concerns about out-of-date data on infrastructure needs and the inconvenience and

inaccessibility of some public transit and paratransit. He noted that TNCs are not sufficient to meet the needs of the disabled community. A trip relies on everything going right. One missing element in the system and the trip fails.

- He stressed the need for new investments in connectivity, smart cities, wayfinding, safe intersection crossing, and other elements.

Dick Alexander, TransDev, discussed the mobility needs of people with disabilities and older adults.

- He described the 3As of accessibility, availability, and affordability.
- He suggested that public entities typically do not want to host data and expect private industry to handle all the data.
- He also suggested that paratransit services do not want to become too successful or more people will use it, resulting in additional costs and resources.
- He noted that the availability of real-time data on malfunctioning equipment, construction, or other types of disruption along the trip route is very important for trip completion.
- He suggested that mobility in the future will focus on PACE: Personalized, Autonomous, Connected, and Electric.

SUGGESTED ACTION ITEMS

- Participants discussed that making datasets available on construction activity, road and sidewalk roughness indices, and other elements, and standardizing those datasets would help facilitate better integration and interoperability of technologies and applications for accessible transportation. Participants suggested that research identifying those datasets and techniques for better integration would be beneficial.
 - A related research topic identified by participants was developing data on geo-location, dynamic, and real-time information on infrastructure assets to analyze, plan, and support new investments.
 - Research developing a collaborative process to review, analyze, and develop or make recommendations for updated sets of standards, policies, and regulatory frameworks for universal accessibility was suggested by participants.
 - Participants suggested that research examining methods to integrate automation solutions into human service transportation for people with disabilities and older adults in both urban and rural areas would be beneficial.
 - Participants noted that individuals with disabilities have similar needs as other groups. As a result, AV design that accommodates the varied needs and challenges of all groups is important and brings a feeling of inclusion to all groups.
 - Participants discussed that data in silos has limited value. Industry methods to integrate data sources into associated needs and services (e.g., connected citizens, care givers, safety alternatives) were identified by participants as a needed research area.
 - Participants noted that technology is changing at a very rapid pace and the different industries need to work together to develop integrated solutions in planning and design stages.

Research to identify integrated approaches and to use the approaches was suggested as a follow-up action item.

- Participants suggested the need for research exploring collaborative efforts to review, analyze, and develop or make recommendations for updated sets of standards, policies, and regulatory frameworks for universal accessibility for use by all elements of the transportation industry.

APPENDIX Y

Breakout Session 25: Ethical and Social Implications

ORGANIZERS

Noah Goodall, *Virginia Transportation Research Council*; Norio Komoda, *Sakura Associates LLC*; Yuri Gawdiak, *NASA*; Filippo Santoni de Sio, *TU Delft*; and Brant Horio, *LMI*

REPORTERS

Noah Goodall, *Virginia Transportation Research Council*

SESSION FOCUS

This breakout session examined the ethical and social challenges of vehicle automation beyond the legal, policy, and technical issues discussed in other sessions. The session focused on two topics: the ethical aspects of routine driving decisions and vehicle design, and the industry responses to the “ethical considerations” guidance in the NHTSA’s *Automated Vehicle Policy* document. The goal of the session was to identify relevant research needs and suggested action items.

ETHICS OF ROUTINE DRIVING

Introduction

Noah Goodall, *Virginia Transportation Research Council*

- The trolley problem and similar dilemmas, where an AV must make a life-or-death choice, is an extremely narrow and difficult situation a car might encounter.
- Much more common are the scenarios that involve the risk of crashing rather than actually crashing.

Selina Pan, *Ford Motor Company*

- Different environments require different styles of driving. Urban, suburban, and rural roads represent unique challenges and different opportunities.
- Driving software must contend with regional differences in driver behavior, and must accommodate certain socially accepted violations of the road law from adjacent human-driven vehicles.

Erik Stayton, *MIT*

- Focus should be not only on creating an ethical AV, but also on creating AVs ethically.
- There are important noncrash risks to consider: environmental, economic, social, and biological. One could eliminate pedestrian deaths by making driving extremely attractive, but this would generate new health risks.

Discussion

- Participants discussed that airlines deal with similar ethical issues, but in a different way. In an event of a passenger airplane being hijacked, there has been discussion in Europe of when it may be appropriate to shoot it down. This is one example of where utilitarian risk assessment falls short—one has a greater claim to safety when on a passenger flight compared when in a car, just as when in a living room versus on a street.
- Participants discussed that it is not clear how much input consumers should have into their vehicles' operation, e.g., speeding. Settings should be somewhat uniform across manufacturers. Education and transparency are crucial to safe operation and public acceptance. This is expected to be a bigger issue with privately owned vehicles. Most people have no problem riding in taxis, and obviously there is no knowledge of the driver's ethics. As most people's first experiences with vehicle automation may well be through ridesharing services, the opportunity exists to use these early deployments to gain a better understanding of drivers' desire for customizable ethics settings.

RESPONDING TO NHTSA'S GUIDELINES ON ETHICAL CONSIDERATIONS

Introduction

Noah Goodall, *Virginia Transportation Research Council*

- NHTSA's Federal Automated Vehicle Policy from September 2016 lists 15 items for developers to address in the future, one of which is "ethical considerations."
- NHTSA sees ethics as conflicts among the three goals of driving: safety, mobility, and legality. Some conflicts may be within one goal, such as balancing the safety of an AVs passenger with the safety of a passenger in another vehicle.

Michele Kyrouz, *Regulatory lawyer and host of the podcast Smarter Cars*

- It is not entirely clear what constitutes an ethics approach that was developed, in the words of NHTSA, "consciously and intentionally." Does this mean "thought about" or "supported by existing research on preferences of potential passengers" or something closer to an organization's philosophy, such as a code of ethics? Safety decisions are being made regularly, but the reasoning behind them is opaque.
- Transparency is important, but it is possible to go too far. One might know in advance how a certain make and model AV will behave in a given situation, and use that knowledge to take advantage of the vehicle.

Stephen Zoepf, *Stanford University*

- Many AV developers have commented on the ethics section of NHTSA’s 2016 guidance. Most argued that more research was needed before the section could be adequately addressed, while global automakers asked for relief from the safety–legality conflict, and to instead allow exceptions for AVs in the regulation.
- Developers should demonstrate expertise in designing ethical AVs. This can be done by hiring experts, positioning them appropriately in the organizational chart, and involving them at every stage of the design process.

Discussion

- It was noted that German regulators do not allow one to differentiate among people based on any factors, e.g., age, health, but require prioritizing human life over property.
- Discussed that recent Congressional discussions on AV regulation have not mentioned ethics, indicating that the guideline may be removed in future editions. [Note: The version released after AVS 2017 in September no longer had an ethics guideline.]
- Participants discussed that some developers have expressed concern about sharing specific algorithms, requesting that these be kept confidential. In order to keep their ethics algorithms private, developers would probably submit two versions, one with high-level philosophies for the public, and another with confidential business information.
- It was suggested that developers may prefer a standard for vehicles ethics, rather than trying to develop and market their own individual philosophies.
- Participants suggested that many of these ethical and safety dilemmas disappear when you protect a vehicle’s environment through dedicated lanes and AV-only zones.
- Participants discussed that the question should not be “did the car make a mistake?” but rather “would this have happened had a human been driving?”

SUGGESTED ACTION ITEMS

- Encourage AV developers to comply with NHTSA ethics guidelines (or other future requirements) by demonstrating competency by hiring experts, then integrating them into the entire design process.
- Study early automated TNC deployments for customers’ revealed preferences for ethical behavior.
- Consider ethics of AVs beyond crash events, considering both routine driving that generates risk, as well as societal, psychological, and economic impacts.
- Research needs:
 - Identify the limits of utilitarian reasoning in AV ethics.
 - Study the differences between passenger’s stated preferences and revealed preferences for AV behavior, particularly in morally ambiguous situations.
 - Study the effect of data availability on crash investigation outcome, specifically determining the minimum amount of data required to determine fault.
 - Review the experiences of integrating risk into liability estimates from the use of robots in industrial settings.

APPENDIX Z

List of Acronyms

AADT	Annual average daily traffic
AAMVA	American Association of Motor Vehicle Administrator
AASHTO	American Association of State Highway and Transportation Officials
ACC	adaptive cruise control
ACM	American Center of Mobility
ADA	Americans with Disabilities Act
ADAS	advanced driver assistance systems
ADS	advanced design system
AI	Artificial intelligence
AMS	analysis, modeling, and simulation
ART	advanced rapid transit
ARTCC	Air Route Traffic Control Centers
ASD	aftermarket safety devices
ASH	architecture, standards, and harmonization
ATA	American Trucking Association
ATC	Aberdeen Test Center
ATTRI	Accessible Transportation Technologies Research Initiative
AUVSI	Association for Unmanned Vehicle Systems International
AV	automated vehicles or autonomous vehicles
AVS	Automated Vehicle Symposium
AVT	advanced vehicle technologies
BEV	battery electric vehicles
BRT	bus rapid transit
BSM	basic safety messages
CACC	cooperative adaptive cruise control
CARMA	Connected Automation Research for Modeling and Analysis
CAV	connected and automated vehicles
CDOT	Colorado Department of Transportation
CMU	Carnegie Mellon University
DLC	discretionary lane change
DMV	Department of Motor Vehicles
DOE	Department of Energy
DOT	Department of Transportation
DSRC	dedicated short range communication
DVI	driver–vehicle interface
EAD	eco-approach and departure
EC	European Commission
EDR	electronic data recorders
EEBL	electronic emergency brake light
EEMS	Energy Efficient Mobility Systems
EMS	emergency medical services

ETP	European Technology Platform
EU	European Union
EV	electric vehicle
FCA	forward collision alert
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FMVSS	Federal Motor Vehicle Safety Standards
FOT	free on truck
FTA	Federal Transit Administration
GHG	greenhouse gases
GLOSA	Green Light Optimal Speed Advisory
GM	General Motors
GPR	ground penetrating radar
HACV	highly automated commercial vehicles
HAV	highly automated vehicles
HCI	host controller interface
HD	high definition
HMI	human-machine interface
HOV	high-occupancy vehicle
IDeA	Inclusive Design and Environmental Access
IIHS	Insurance Institute for Highway Safety
ISTEA	Intermodal Surface Transportation Efficiency Act
IT	information technology
ITF	International Transport Forum at the OECD
ITS	intelligent transportation systems
MaaS	mobility as a service
MARAD	Maritime Administration
MIT	Massachusetts Institute of Technology
MK	Milton Keynes
ML	machine learning
MOD	mobility on demand
MUTCD	Manual on Uniform Traffic Control Devices
NACTO	National Association of City Transportation Officials
NAHSC	National Automated Highway Systems Consortium
NASA	National Aeronautics and Space Administration
NCHRP	National Cooperative Highway Research Program
NDS	Navigation Data Specifications
NHTSA	National Highway Traffic Safety Administration
NIST	National Institute of Standards and Technology
OADF	Open Autodrive Forum
OBU	onboard units
ODD	operational design domain
ODE	operational data environment
OEDR	object and event detection and response
OEM	original equipment manufacturers
OH	out-of-home

OTA	over the air
PATH	Partners for Advanced Transportation Technology
PAVE	Practical Autonomous Vehicle Exemptions
PHEV	plug-in electric vehicles
PRT	personal rapid transit
PSTA	Pinellas Suncoast Transportation Agency
RDE	research data exchange
RFP	request for proposals
ROI	return on investment
RSU	roadside unit
SAAV	Safety Assurance of Automated Vehicles
SAFE	Securing America's Future Energy
SAM	seamless autonomous mobility
SCAG	Southern California Association of Governments
SDN	software-defined networking
SFCTA	San Francisco County Transportation Authority
SI	swarm intelligence
SIP	Strategic Innovation Promotion
SMART	Systems and Modeling for Accelerated Research Transportation
SoA	service-orientated architecture
STRIA	Strategic Transport Research and Innovation Agenda
TCRP	Transit Cooperative Research Program
TMC	transportation management centers
TNC	transportation network companies
TOC	traffic operations center
TRB	Transportation Research Board
TRC	Transportation Research Center
TRI	Toyota Research Institute
TRL	technology readiness level
TSS	Transport Simulation Systems
TSU	Texas Southern University
TT	travel time
UC	University of California
UCLA	University of California Los Angeles
UK	United Kingdom
UNR	University of Nevada, Reno
USMC	U.S. Marine Corps
VAD	vehicle awareness device
VMT	vehicle miles traveled
VOT	value of time
VR	virtual reality
VRU	vulnerable road users
VTTI	Virginia Tech Transportation Institute

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