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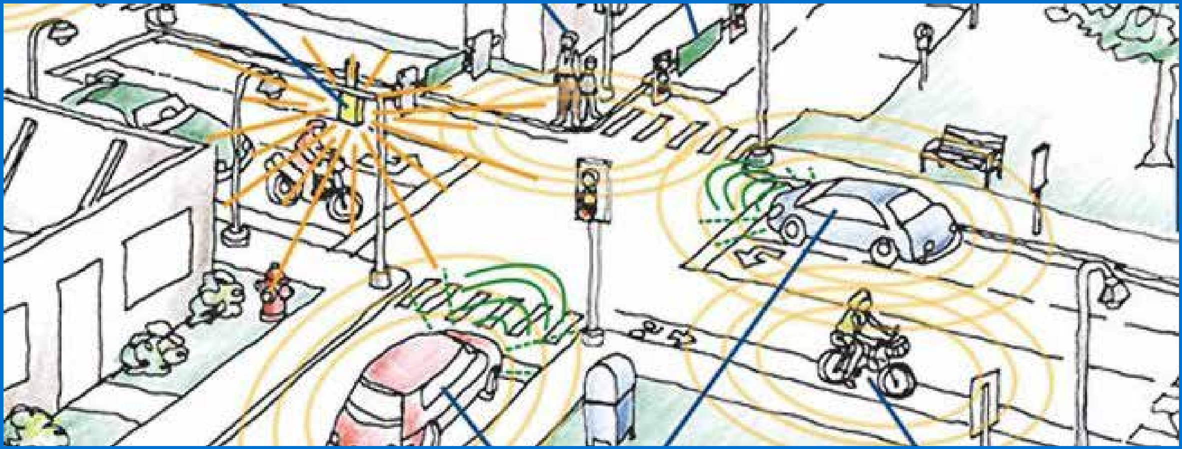
Automated and Connected Vehicles

Summary of the 9th University Transportation Centers Spotlight Conference

November 4–5, 2015
Washington, D.C.



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Summary of the 9th University Transportation Centers Spotlight Conference

Katherine F. Turnbull
Texas A&M Transportation Institute
Rapporteur

November 4–5, 2015
The National Academy of Sciences Building
Washington, D.C.

Supported by
University Transportation Centers Program

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Office of the Assistant Secretary for Research and Technology
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This project was sponsored by the Office of the Assistant Secretary for Research and Technology, U.S. Department of Transportation, and the Transportation Research Board.

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Learn more about the Transportation Research Board at **www.TRB.org**.

Preface

Connected vehicle (CV) and automated vehicle (AV) technologies are being developed, tested, and deployed by a variety of private companies and public agencies. CVs and AVs may improve safety, reduce emissions, and improve the efficiency and reliability of the transportation system. The Transportation Research Board (TRB) hosted a conference entitled *Automated and Connected Vehicles* at the National Academy of Sciences Building in Washington, D.C., in November 2015. Speakers highlighted research, testing, and deployment activities under way at the national, state, and local levels. Other speakers provided perspectives from the insurance industry, self-driving technology and mapping companies, and carsharing businesses.

The meeting was the ninth in a series of Spotlight Conferences funded by the U.S. Department of Transportation's (U.S. DOT) Office of the Assistant Secretary for Research and Technology (OST-R), which sponsors the University Transportation Centers (UTC) Program. The UTC Program awards grants to universities across the country to advance the state of the art in transportation research, to conduct technology transfer activities, and to educate the next generation of transportation professionals.

TRB assembled a planning committee, appointed by the National Research Council, to organize and develop the conference program. The planning committee was chaired by Melissa Tooley from the Texas A&M Transportation Institute (TTI). Committee members provided expertise in AV and CV technology, planning, public policy, operations, and energy.

The planning committee was responsible solely for organizing the conference, identifying speakers, reviewing submitted poster abstracts, and developing topics for the breakout group discussions. Katherine Turnbull, TTI, served as the conference rapporteur and prepared this document as a factual summary of what occurred at the conference. Responsibility for the published conference summary rests with the rapporteur and the institution.

The conference attracted 151 participants. Agency personnel responsible for technology, planning, policy, operations and maintenance, and performance management joined faculty, students, and researchers from UTCs and other universities to explore issues and opportunities associated with testing and deploying AVs and CVs. Representatives from the private sector, including technology companies, shared mobility services, and the insurance industry, also participated in the conference. The conference, which was characterized by broad and active participation and discussion, considered potential research to address issues associated with AV and CV deployment.

The conference began with an overview of AV and CV programs, issues, and opportunities. Four plenary sessions focused on institutional and policy issues, infrastructure design and operations, planning, and modal applications. Conference participants also had the opportunity to interact with poster authors and to discuss issues and areas for further research in breakout groups based on the four plenary session themes. Speakers in the closing plenary session highlighted topics and research needs discussed in the breakout sessions.

These proceedings consist of presentation summaries from the plenary sessions. A list of the posters is provided in Appendix A. 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 conference participants, the conference planning committee members, TRB, or the National Academies of Sciences, Engineering, and Medicine. The conference PowerPoint presentations are available at http://onlinepubs.trb.org/onlinepubs/conferences/2015/UTC/Program.pdf.

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise in accordance with procedures approved by the National Research Council Report Review Committee. The purposes of this independent review are to provide candid and critical comments that will assist the institution in making the published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the project charge. The review comments and draft manuscript remain confidential to protect the integrity of the process.

TRB thanks the following individuals for their review of this report: Robert Bertini, California Polytechnic State University, San Luis Obispo; Larry Head, University of Arizona; Robert Johns, Volpe National Transportation Systems Center; Gregory Krueger, HNTB Corporation; and John Mason, Auburn University.

Although these four reviewers provided many constructive comments and suggestions, they did not see the final draft of the summary. The review of this summary was overseen by Susan Hanson of Clark University (emerita). Karen Febey, TRB Senior Report Review Officer, managed the review process.

The conference planning committee thanks Katherine Turnbull for her work in preparing this conference summary report and extends a special thanks to the U.S. DOT OST-R for providing the funding support and active staff participation that made the conference possible.

Acronyms

AAMVA	American Association of Motor Vehicle Administrators
AV	automated vehicle
CACC	cooperative adaptive cruise control
CAV	constant angular velocity
CPS	cyber-physical systems
CPS-SSG	Cyber-Physical Systems Senior Steering Group
CV	connected vehicle
DMV	Department of Motor Vehicles
DOE	U.S. Department of Energy
DOT	department of transportation
DSRC	dedicated short-range communication
DUAP	data use analysis and processing
FHWA	Federal Highway Administration
FMVSS	Federal Motor Vehicle Safety Standards
FOT	Field Operational Test
IoT	Internet of things
ITS	intelligent transportation systems
JPO	ITS Joint Program Office
MPO	metropolitan planning organization
MTC	University of Michigan Mobility Transformation Center
NASA	National Aeronautics and Space Administration
NHTSA	National Highway Traffic Safety Administration
NIH	National Institutes of Health
NIST	National Institute of Standards and Technology
NITRD	Networking and Information Technology Research and Development
NSF	National Science Foundation
OEMs	original equipment manufacturers
OST-R	Office of the Assistant Secretary for Research and Technology
OSU	Ohio State University
SHRP 2	second Strategic Highway Research Program
SMART	Systems and Modeling for Accelerated Research in Transportation
TRB	Transportation Research Board
TSM&O	transportation systems management and operation
TTI	Texas A&M Transportation Institute

U.S. DOT	U.S. Department of Transportation
UTC	University Transportation Center
V2I	vehicle-to-infrastructure
V2V	vehicle-to-vehicle
VMT	vehicle miles traveled

Contents

OPENING SESSION

Overview of Automated and Connected Vehicle Issues and Progress

Melissa Tooley, *Texas A&M Transportation Institute and Chair, Conference Planning Committee*
Keith Marzullo, *Federal Networking and Information Technology Research Development Program, National Coordination Office*
Kevin Dopart, *ITS Joint Program Office, U.S. Department of Transportation*
Ron Medford, *Google, Inc.*
Jane Macfarlane, *HERE*

CONFERENCE WELCOME

Melissa Tooley

Melissa Tooley welcomed participants to the 9th University Transportation Center Spotlight Conference: Automated and Connected Vehicles. She recognized the individuals and agencies responsible for organizing and sponsoring the conference and reviewed the program. Tooley covered the following topics in her opening remarks:

- Organized by the Transportation Research Board (TRB) of the National Academies, the conference was sponsored by the Office of the Assistant Secretary for Research and Technology (OST-R) at the U.S. Department of Transportation (U.S. DOT). Tooley acknowledged and thanked Robin Kline and Tom Bolle, OST-R, and Richard Cunard and Freda Morgan, TRB, for their assistance in organizing the conference. She also welcomed the students attending the conference. She introduced members of the Conference Planning Committee, recognizing their hard work in developing outstanding sessions with excellent speakers.
  - Robert Bertini, California Polytechnic State University, San Luis Obispo, Modal Applications Track Chair
  - Chandra Bhat, University of Texas, Austin
  - Mara Campbell, CH2M
  - Charles Howard, Puget Sound Regional Council, Planning Track Chair
  - Edward Hutchinson, Florida Department of Transportation
  - John Maddox, Mobility Transformation Center, University of Michigan
  - Zach Rubenstein, Carnegie Mellon University

- Steven Shladover, California Partners for Advanced Transportation Technology, Institutional and Policy Track Chair
- Karlyn Stanley, RAND Corporation
- Patrick Szary, Center for Advanced Infrastructure and Transportation, Rutgers University, Infrastructure Design and Operations Track Chair
- Stanley Young, National Renewable Energy Laboratory and University of Maryland

• Tooley noted that connected vehicle (CV) and automated vehicle (AV) technologies have the potential to effect disruptive change, not just to transportation but to society's way of life. This change would occur not only on the nation's roadways, but across all modes of transportation. She suggested that CV and AV technologies could improve safety, reduce harmful emissions, and improve efficiency and reliability. She further suggested that a fully connected transportation system could change the principles of transportation engineering. For example, sight distance could become irrelevant and traffic signals obsolete. She also commented that the benefits of these technologies could remain unrealized if concerns about data security, privacy, and other issues were not adequately addressed.

• Tooley indicated that the conference provided the opportunity to discuss these issues and opportunities. She noted that the conference was organized around the four general subject clusters identified in National Cooperative Highway Research Program Project 20-24(98), Connected/Automated Vehicle Research Roadmap, which was conducted for the American Association of State Highway and Transportation Officials. The four subject clusters were institutional and policy, infrastructure design and operations, planning, and modal applications.

• Tooley reviewed the conference program. The opening session provided an overview of general interest topics to set the tone for the conference. Each plenary session focused on one of the subject clusters, with speakers representing the perspectives of academia, industry, and government at all levels. After the general sessions, breakout groups allowed participants to share their perspectives on the state of the practice in CV and AV and to identify areas for further research. The closing session featured summaries from the breakout groups.

INFORMATION TECHNOLOGY RESEARCH AND DEVELOPMENT FOR SMART CITIES AND CONNECTED COMMUNITIES: A CROSS-AGENCY FRAMEWORK

Keith Marzullo

Keith Marzullo discussed the responsibilities and activities of the federal Networking and Information Technology Research and Development (NITRD) program. He described the NITRD organization structure and the Cyber-Physical Systems Senior

Steering Group (CPS-SSG), which is tasked with coordinating efforts for smart cities and connected communities. He reviewed the CPS-SSG vision, goals, and desired outcomes and benefits and highlighted the roles of the participating agencies and the activities currently under way. Marzullo covered the following topics in his presentation:

- The NITRD program was established by the High-Performance Computing Act of 1991 (Public Law 102-194), which Marzullo noted was in the early days of the Internet. He reviewed the purpose of NITRD, which is "to assure U.S. leadership in, and accelerate development and deployment of, advanced networking, computing systems, software, and associated information technologies." He reported that NITRD helps coordinate activities across 21 federal agencies and offices. NITRD is overseen by the National Coordination Office, which provides technical expertise, planning, and coordination, as well as serving as the central point of contact. The National Coordination Office vision is "to be a catalyst for collaboration, information exchange, and outreach to foster knowledge, methods, research and development, technology transfer, and innovation to meet the NITRD Program goals." Marzullo presented the NITRD organizational structure, which includes the National Coordination Office reporting to the White House Executive Office of the President, Office of Science and Technology Policy, as well as a link to the National Science and Technology Council, Committee on Technology Subcommittee on NITRD. He noted there are numerous coordination and steering groups coordinating different activities across agencies.
- Marzullo described CPS-SSG, which is composed of individuals from different federal agencies with budget authority. He described examples of cyber-physical systems (CPS) and noted that autonomous vehicles fall within the program of the CPS-SSG. Marzullo described the CPS-SSG smart cities and connected communities framework. Elements of the framework include energy-efficient power grids, smart cars and safe highways, earthquake-proof buildings, smart planes for safe air travel, and many other features (see https://www.nitrd.gov/sscc).
- Marzullo noted that communities in all settings and at all scales have access to information, advanced technologies, and smart services that enhance the sustainability and quality of life, improve health and safety, and help provide economic prosperity for their residents. He reported that CPS-SSG was coordinating efforts among federal agencies and with public–private partnerships for smart cities and connected communities. Examples of activities included funding and performing foundational research and accelerating innovation and transition in scalable and replicable smart city solutions. Another activity he described is applying advanced CPS concepts, coupled with sociotechnical system understanding, to integrate city-scale information technology and physical infrastructures. He also noted that CPS-SSG was promoting

discovery, innovation, and entrepreneurship in smart city technologies and facilitating the application of CPS concepts to make cities more livable, workable, safe, and sustainable.

• Marzullo reviewed the goals of CPS-SSG. The first goal was creating next-generation capabilities by leveraging fundamental research and development in CPS, smart systems, sociotechnical systems, and other emerging technologies, processes, and policies. The second goal was supporting the research and development necessary to create smart cities by using data analytics to enhance individuals' quality of life and to improve their health, safety, and economic prosperity. The third goal was building and expanding access to the smart cities and connected communities resources—both domain specific and shared—that are needed for agencies to best achieve their mission goals and for the country to innovate and benefit. The fourth goal was to promote interoperable, standards-based smart city solutions that reduce deployment costs and enable modular architectures that are flexible and adaptable in meeting a community's needs. The final goal was to improve education and training opportunities to fulfill increasing demands for analytical talent and capacity for the broader workforce to support smart cities and connected communities.

• Marzullo reviewed the anticipated outcomes of the CPS-SSG activities, which included the application of innovative technologies to enhance sustainable livelihoods and the quality of life in cities. Another anticipated outcome was fostering smart citizens by providing the education and tools necessary to create a smart city workforce and a citizenry able to benefit from smart city solutions. Promoting partnerships across federal agencies and with stakeholders in industry, academia, and other government entities to achieve positive outcomes represented another outcome. The final anticipated outcome was the development of pilots and smart city deployments that demonstrate value, feasibility, sustainability, and resiliency.

• Marzullo described the anticipated benefits from the various activities, which included economic growth and new jobs in businesses that are globally competitive in smart city technologies, increased safety and mobility of roadway travelers and reduced traffic-related pollution, and reduced energy consumption for human mobility, buildings, and commercial operations. Other potential benefits he identified were faster and more resilient wired and wireless communications, improved response and recovery to natural and human-made disasters, improved monitoring of air and water quality, and reduced crime. Increased private-sector investment in new and growing businesses, increased safety of infrastructure from condition-based monitoring, expanded public participation, and improved healthcare and aging in place represented additional benefits.

• Marzullo reviewed the participating agencies and the activities currently under way. He noted that the National Institute of Standards and Technology (NIST) and the National Science Foundation (NSF) were the two leading groups promoting current activities. He discussed the NIST Global City Teams Challenge, which brings together teams of cities and innovators working in partnership to use technologies to improve the safety, sustainability, livability, and workability of communities worldwide. He also noted that NIST was using open, consensus-based public working groups to develop a comprehensive framework for the design, evaluation, and operation of complex CPS, including smart city technologies. Finally, through the Smart Grid program and the public–private Smart Grid Interoperability Panel, NIST is working with the private sector on smart grid interoperability and security standards that enable the intelligent use of energy resources as a key component of smart city solutions. He also noted that through the National Cybersecurity Center of Excellence, NIST is providing businesses with real-world cybersecurity solutions based on commercially available technologies for smart city applications in energy, transportation, and finance. Further, NIST is promoting the emergence of voluntary, consensus-based international standards that enable interoperable smart city solutions to speed deployment efforts, increase flexibility and capability, reduce costs, and catalyze the emergence of a vibrant and global smart city technologies market.

- Marzullo noted that NSF brings together academic researchers, industrial and nonprofit partners, and local cities, municipalities, and regions to integrate data sources, networked computing systems, and infrastructure to enhance the quality of life within communities across health and wellness, energy efficiency, building automation, and transportation. He also noted that NSF supports fundamental research on intelligently and effectively designing, adapting, and managing smart and connected communities. He noted that NSF had recently released a “Dear Colleague” letter on projects related to smart cities, including transportation.
- Marzullo reviewed the interest from the U.S. DOT, which included research and deployment of innovative transportation technologies to reduce or eliminate deaths and serious injuries among all users of the transportation system; to increase the reliability and efficiency of the transportation system; and to provide safe and affordable mobility options. Increasing the service life and optimizing the maintenance of transportation infrastructure, reducing the environmental and energy impacts of the transportation system, and increasing the resilience of the transportation system represented additional areas of interest to the U.S. DOT.
- According to Marzullo, the U.S. Department of Energy’s (DOE) Office of Electricity Delivery and Energy Reliability has two major programs in the topic area. The Cybersecurity for Energy Delivery Systems program is working toward resilient energy delivery systems that are able to survive a cyber incident. The Smart Grid Integration Challenge for Cities is a challenge competition to recognize U.S. cities as smart city leaders in implementing sensing, data sharing, and data analytics toward achieving energy consumption reduction targets set by individual cities.
- Marzullo reported that the National Institute of Food and Agriculture, within the U.S. Department of Agriculture, is exploring two major topic areas. The first topic is increasing food and nutritional security through the development of high-output

and efficient urban agriculture technologies and systems, such as vertical farming. The second interest area is developing more resilient, robust, and reliable agricultural systems while faced with a changing climate and an increasing global population.

• According to Marzullo, the National Institutes of Health (NIH) has a broad interest in the smart cities topic. Enhancing collaboration between researchers, smart citizens, local cities and municipalities, and other stakeholders to evaluate the health-related benefits of networked sensors, infrastructure, and computing systems represents one area of interest. He noted that NIH is also supporting research that develops, implements, and evaluates health-related CPS in smart cities with consideration of security, privacy, health disparities, and human factors. Fostering the development of interoperability and consensus standards that will ensure that appropriate technologies are safe, effective, and sustainable represents still another NIH interest. Additionally, he noted that NIH is interested in promoting a citizen-centric, data-driven system that embraces personalized health information and care options and is capable of learning.

• The National Aeronautics and Space Administration (NASA) was the final agency highlighted by Marzullo. He noted that NASA was interested in applying collaborative, planning, and scheduling applications to enhance multimodal smart cities traffic-flow management systems. NASA is also interested in helping accelerate safe and efficient future unmanned aerial vehicle operations for smart cities services, operations, and new businesses. NASA has a further interest in sharing and promoting the next generation of verification and validation tools to enable smart city developers with the means to assure high integrity, robust, and interoperable complex systems.

U.S. DEPARTMENT OF TRANSPORTATION CONNECTED AND AUTOMATED VEHICLE RESEARCH UPDATE

Kevin Dopart

Kevin Dopart discussed CV and AV research at the U.S. DOT. He described the three recently awarded CV pilots, anticipated benefits from CV and AV deployment, and current research tracks and projects. Dopart covered the following topics in his presentation:

• Dopart noted that the Intelligent Transportation Systems (ITS) Joint Program Office (JPO) was the major internal investor in research related to CVs and automation within the U.S. DOT. He reported that the recently released U.S. DOT ITS Strategic Plan for 2015–2019 includes two strategic priorities. The first strategic priority focuses on realizing CV implementation. It builds on the substantial progress made in recent years planning, designing, and testing for CV deployment across the nation. The second strategic priority is advancing automation. This priority shapes the ITS program around research, development, and adoption of automation-related technologies as they emerge.

• Dopart highlighted recent and upcoming CV milestones at the U.S. DOT. The National Highway Traffic Safety Administration (NHTSA) Advanced Notice of Proposed Rulemaking on vehicle-to-vehicle (V2V) communications was released in August 2014. The U.S. DOT announced the first wave of CV pilots in September 2015. He noted that the Federal Highway Administration (FHWA) would be releasing guidance documentation on vehicle-to-infrastructure (V2I) in December 2015 and that NHTSA is scheduled to send the Notice of Proposed Rulemaking requiring dedicated short-range communication (DSRC) radios on all new light-duty vehicles for economic review in December 2015, with publication in the Federal Register anticipated in early 2016.

• Dopart described the three CV pilots recently awarded to Tampa, Florida; New York City, New York; and the State of Wyoming. He noted that the pilots in Tampa and New York City have an urban focus on arterials, expressways, intersections, and pedestrian safety, while the Wyoming pilot has a freight focus in the I-80 corridor. He reviewed the schedule for the pilots. Phase 1 includes up to 12 months for concept development. Phase 2 includes up to 20 months for design, deployment, and testing. Phase 3 involves a minimum of 18 months for maintaining and operating the pilot. He noted there is a decision point at the end of Phase 1 and again at the end of Phase 2, and commented that although it is expected the pilots will all move forward into the next phase, it is not a given. There is also the expectation that the pilots will transition into ongoing operation at the end of Phase 3. He noted there will be both self-evaluations and independent evaluations of the pilots.

• Dopart described some of the anticipated benefits from automation, which focus primarily on improving safety, increasing mobility and accessibility, and reducing energy use and emissions. Anticipated safety benefits include reducing and mitigating crashes. Potential mobility and accessibility benefits include expanding the capacity of roadway infrastructure, enhancing traffic-flow dynamics, and providing more personal mobility options for disabled and aging population groups. Energy use and emissions benefits may result from aerodynamic "drafting" and improved traffic-flow dynamics.

• Dopart commented that connectivity is critical to achieving the greatest benefits. He noted that autonomous vehicles operate in isolation from other vehicles by using internal sensors, but CVs communicate with nearby vehicles and the infrastructure. Connected AVs leverage autonomous and CV capabilities to maximize potential benefits.

• Dopart described the five ITS JPO automation program research tracks: enabling technologies, safety assurance, transportation system performance, testing and evaluation, and policy and planning. The first research track focuses on enabling technologies. Dopart presented examples of applications of enabling technologies, including positioning, navigation, and timing and mapping, communications, and sensors.

• The second research track addresses safety assurance. Dopart presented an example of human factors research associated with the transition between automated and nonautomated modes. He described a study conducted at the Virginia Tech Transportation Institute for NHTSA that examined driver reengagement at Level 2 and Level 3 automation. Information on the project is available at http://www.nhtsa.gov/DOT/NHTSA/NVS/Crash Avoidance/Technical Publications/2015/812182_HumanFactorsEval-L2L3-AutomDrivingConcepts.pdf.

• The third research task is transportation system performance. Dopart reported that this track focuses on internal U.S. DOT application and prototype development. He indicated that research on human-in-the-loop Level 1 connected automation is under way.

• The fourth research track is testing and evaluation. Dopart described the benefits evaluation framework illustrated in Figure 1 that was developed by the U.S. DOT. It highlights all the potential elements, from safety to land use, that may be influenced by AV and CV deployment. He reported that the framework would be applied in quantitative analyses over the next few years.

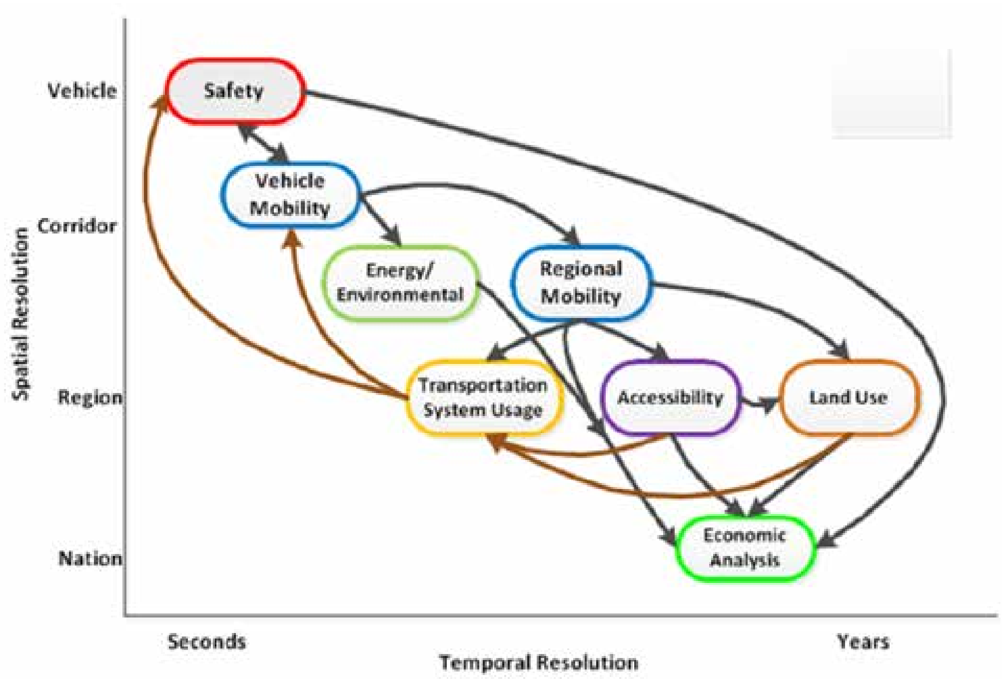

FIGURE 1 Benefits testing framework.
(Source: ITS Joint Program Office, U.S. Department of Transportation.)

TABLE 1 Example Systems at Each Automation Level

SAE Level	*Example Systems*	*Driver Roles*
1	Adaptive cruise control OR Lane-keeping assistance	Must drive other functions and monitor driving environment
2	Adaptive cruise control AND Lane-keeping assistance Traffic jam assist	Must monitor driving environment (system nags driver to try to ensure it)
3	Traffic jam pilot Automated parking Highway autopilot	May read a book, text, or web surf, but must be prepared to intervene when needed
4	Closed campus driverless shuttle Valet parking in garage “Fully automated” in certain conditions	May sleep, and system can revert to minimum risk condition if needed
5	Automated taxi Carshare repositioning system	No driver needed

SOURCE: California PATH.

• The fifth research track is policy and planning. Dopart presented an example of the review of Federal Motor Vehicle Safety Standards (FMVSS). The project is examining how highly automated vehicles may change the nature of the FMVSS and is identifying where current FMVSS pose challenges to the introduction of AVs. He noted that the project, which represents NHTSA and ITS JPO coordinated research, will also help ensure that NHTSA regulations do not stifle innovation. He described the difference between wording such as “activate braking” and “step on the brake.” Other policy research topics being examined include privacy concerns, societal acceptance, and federal roles, especially related to state and local coordination.

• Dopart discussed the spotlight area of Level 1 connected automation. He reviewed the information in Table 1, which was developed at California PATH. The example systems in Level 1 are adaptive cruise control and lane-keeping assistance, which are currently available in some vehicles. He noted the research in this area is focusing primarily on human-in-the-loop issues associated with longitudinal controls. He noted that connected automation research and development at the U.S. DOT are focusing on cooperative adaptive cruise control (CACC) development, freeway operations applications, eco-approach and -departure at traffic signals, and truck platooning. Research is being funded and coordinated between ITS JPO and FHWA. He indicated that the projects are being led by FHWA personnel at the Turner–Fairbank Highway Research Center.

• Dopart reviewed the CACC development projects, which are focused on enabling CACC high-performance vehicle streams and CACC field tests. He noted that many of the automotive companies, including Volvo and Tesla, are assessing CACC concepts and prototypes. He also reported that studies of driver acceptance of Level 1 applications using driving simulators are under way at the Turner–Fairbank Highway Research Center.

• Dopart described the freeway traffic operations applications being examined, including freeway speed harmonization and lane changing–merging operations. He also discussed testing the Eco Glidepath at signalized intersections. He noted that numerous field tests have been conducted at the Turner–Fairbank Highway Research Center with a single vehicle at a single intersection without traffic. A tablet-based driver interface was used to provide the driver with signal phase and timing data.

• Dopart discussed the truck platooning projects being conducted under the advanced exploratory research program. The first project, which focuses on two-truck platoons, involves Auburn University and Peterbilt. The second project, which involves Caltrans, the University of California at Berkeley, and Volvo, is testing three-truck platoons with longitudinal control. Drivers are still steering in this pilot. He noted that truck platooning provides fuel savings to both the lead and the trailing truck.

• Dopart concluded by highlighting technical and policy challenges associated with advancing CV and AV deployment. He suggested that building realistic public expectations and understanding was a key challenge, as were human factors issues related to disengaging and reengaging in the driving function. Data ownership, privacy, and cybersecurity represented other challenges. The testing and certification complexity for the various components was another challenge. He suggested that harmonizing state and local regulations represented an ongoing challenge.

PROGRESS TO FULLY DRIVERLESS CARS

Ron Medford

Ron Medford discussed recent activities associated with Google self-driving vehicles. He reviewed the mission of the self-driving vehicle team, key elements of self-driving vehicles, and recent regulations in California for reporting crashes involving autonomous vehicles and operating self-driving vehicles. Medford covered the following topics in his presentation:

• Medford discussed the mission of the Google self-driving vehicle team, which focuses on transforming mobility and transportation for people. He noted that the only way to accomplish that mission is to take the driver out of the system. That approach provides access to people who cannot drive and accomplishes significant societal benefits. He indicated that the current small, low-speed vehicle, which was announced in May 2014, builds on the success of realizing self-driving vehicles on single-lane freeway driving. He noted that the self-driving vehicle tests on freeways with Google employees indicated that people loved the system, but they tended to overtrust the technology and in some cases did not monitor the road adequately.

• Medford reviewed the three key components of self-driving vehicles: detailed maps, a slate of sensors, and onboard software. He noted that accurate maps are critical as Google self-driving vehicles cannot operate in an area without a map. Lane markings, crosswalks, and other features are layered on the map. Based on the sensor data, predictions are made on what the vehicle will encounter and the information is used to direct the vehicle's speed and path.

• Medford reported that Google provides a monthly update on where the vehicles are driving, the number of miles in operation, and other information. He noted that Google vehicles have driven 2.2 million miles since 2009, with 1.3 million miles in autonomous mode and 0.9 million miles in manual mode. The vehicles in Austin, Texas, and Mountain View, California, are in operation and drive about 10,000 to 15,000 miles on city streets every week. He noted that this mileage was critical for scenario development and simulation, with approximately 3 million miles of simulation completed daily. The current Google vehicles include 23 Lexus (19 in Mountain View and four in Austin) and 25 research prototypes (21 in Mountain View and four in Austin).

• Medford reviewed the final regulations issued in September 2014 by the California Department of Motor Vehicles (DMV) related to testing autonomous vehicles on public roads in the state. He noted that the regulations require groups to obtain a permit to test autonomous vehicles on public streets and to report crashes with self-driving vehicles. The requirements include reporting all crashes to the DMV within 10 days of the occurrence. He noted that Google reviewed records since 2009 and identified 16 crashes: 12 rear-end crashes, three sideswipes, and one front-end crash. He noted that the rear-end crashes involved another vehicle running into a Google vehicle stopped at a traffic signal or stop sign. He also said that the front-end crash occurred not during testing but when an employee used the vehicle to run an errand. The vehicle was in manual operating mode in an area that was not mapped, but he noted that in the interest of transparency, Google reported it. Furthermore, he said that although the police responded to some of the crashes, none of the crashes resulted in a formal police report. As a result, none of the crashes were in the formal NHTSA crash database. He suggested that unreported crashes continue to be an issue that NHTSA and other agencies acknowledge. He indicated that Google will continue to report any crashes to the DMV and the public in its monthly report.

• Medford noted that the California legislative deadline for the California DMV to promulgate self-driving vehicle operating regulations was January 1, 2015, and although three workshops were held, the regulations have not yet been finalized. One issue raised at the workshops was defining the process and requirements for safety certification. He noted that in addition to reporting crashes to the California DMV there is also a requirement in California to report occurrences of safety-related disengagements with self-driving vehicles. All companies with testing permits are required to provide this report by January 1, 2016.

• In closing, Medford suggested a few challenging questions and topics for further discussion. One was a public-road driving test for self-driving vehicles. He repeated that the Google mission focuses on providing access to people who cannot drive; thus, a good research topic would be to quantify the social benefits of providing mobility to those individuals. Another topic he suggested was examining the impact of self-driving cars and carsharing on land use in cities, especially the potential to reduce traffic congestion and the need for parking. He closed by sharing a video with anomalies encountered by Google vehicles, including a bird in the road, a bicycle running a red light, and a person in a wheelchair chasing a duck with a broom.

NEXT-GENERATION LOCATION SERVICES

Jane Macfarlane

Jane Macfarlane discussed the use of vehicle probe data and maps for a variety of purposes. Currently coowned by Audi, BMW, and Daimler, HERE produces electronic maps and data for in-vehicle navigation systems and other applications. She described recent advancements in probe data, data analytics, and digital maps. She presented examples highlighting different technologies and applications. Macfarlane covered the following topics in her presentation:

• Macfarlane noted that HERE produces maps for nearly 200 countries and that HERE maps are used in four of the five major in-vehicle navigation systems in the United States and Europe. She commented that HERE maps and data enable mobile, web, and enterprise solutions for global industry leaders.

• Macfarlane discussed the features of new maps, noting that maps can be used to make decisions in real time with real-time data to facilitate travel and other activities. She also noted that the combination of maps and extensive vehicle data currently being collected can be used to provide new metrics. In addition, she noted that the Internet of things (IoT) will generate a new kind of “big data” and will require new analytical tools. She stressed the importance of managing all these data and suggested that there will be a dramatic shift in computing solutions in the future.

• Macfarlane suggested that maps are part of the human DNA, as they have been made since the dawn of civilization. She described the dramatic changes that have occurred in maps and mapping capabilities over the years. Macfarlane presented examples of digital maps, including locating photo-realistic building objects created from photogrammetry on digital maps. She suggested that these types of techniques are turning maps into complex instruments and are enriching the use of maps for analysis and visually portraying information for policy makers and the public.

• Macfarlane discussed the importance of developing and maintaining accurate and up-to-date base maps. HERE and other mapping companies have vehicle fleets that continue to update base maps using LIDAR and other sensors. She presented an example of a 3-D colorized point cloud from LIDAR that portrayed a digital street and building map.

• Macfarlane suggested that a pervasive, data-driven, cloud-enabled IoT was emerging. In addition to a wealth of data from vehicles, she noted that a wealth of data is also available from personal smart phones and other electronic devices that people use every day. She noted that the available data are machine generated, human generated, structured, and unstructured. She suggested that the seven Vs of big data are present: velocity, volume, variety, variability, veracity, visualization, and value. She noted that veracity, or data quality, is an important issue with big data. She commented that although visualization capabilities are extensive, they also require significant computer capabilities.

• Macfarlane reported that it was an exciting time to be working with big data digital maps and data analytics. She suggested that maps are taking on new dimensions and roles. Maps are becoming companions, advisors, and assistants. Maps are listening, reporting, and tracking.

• Macfarlane highlighted examples of mapping HERE GPS probe data from San Francisco, California. She noted that one challenge was making sense of lots of little pieces of data that have been chopped up to address privacy concerns. She presented another example of cell phone trace data in Los Angeles and Amsterdam, both using the HERE visualization package. She presented an example of signature analytics, which shows where people are lingering in Amsterdam.

• Macfarlane described biases in probe vehicle data and noted that the data come from a variety of sources. She presented fleet and customer data from the morning and evening peak periods in the San Francisco Bay Area, which show different patterns. She stressed the importance of understanding limitations and potential biases in data from different sources. She noted that the data define their value and suggested that an important research topic was examining the quality of big data.

• Macfarlane presented maps and analyses from the City of Eindhoven in the Netherlands. She described an analysis examining when drivers applied their brakes approaching a turn on a roadway. The analysis highlights and visually displays the first brake application, last-second braking, lateral acceleration in the northbound and southbound directions, and lateral acceleration during a rain storm. In addition, the analysis highlights the "wisdom of crowds," in that data from more than just one driver are needed to understand how people experience a roadway. She also noted that this type of information can be used in developing and programming AVs, as well as a driver assistance product that can provide advice to inexperienced drivers.

• Macfarlane discussed the benefits of having real-time data on the use of windshield wipers. Broadcasting these data to vehicles in the same area can let drivers know when they are approaching heavy rain. Information on alternate routes to avoid bad weather could also be provided.

• Macfarlane provided examples of future uses of big data analytics to make travel predictions. She described techniques to smooth vehicle probe data to model congestion patterns and the use of sophisticated models to develop continuous learning systems. She described building a model examining every link along Highway 101 in San Francisco and developing 1-day, 2-day, 7-day, weekend, and holiday traffic patterns. Macfarlane described approaches for detecting traffic jams in real time from vehicle probe data. She noted the challenge of distinguishing recurring congestion from traffic jams caused by incidents, especially crashes.

• Macfarlane introduced the idea of geospatially distributed computing. She also suggested that sensors will increase the understanding of context, with contextual services becoming the value-creation mechanism for mobile devices. She further suggested that context equals state plus preference plus hyperlocal understanding and that context is dynamic and changes with time. She described the numerous applications for this type of data, including creating a digital version of a real city.

• In closing, Macfarlane presented the following potential research topics:

- One research topic was examining the veracity or quality of big data and data from the IoT.
- Two other research topics she suggested focused on (a) signal confidence and sensor fusion and (b) semantic feature extraction and big data reduction.
- Geospatially distributed computing and algorithm partitioning and communications represented another research topic.
- A final suggestion was providing better access to data sets for the academic community to enhance research opportunities.

Melissa Tooley, Texas A&M Transportation Institute, presided at this opening session.

PLENARY SESSION 1

Institutional and Policy

Jude Hurin, *Nevada Department of Motor Vehicles*
Chris Gerdes, *Stanford University*
Reuben Sarkar, *U.S. Department of Energy*
Edward Collins, *Allstate Insurance*

AMERICAN ASSOCIATION OF MOTOR VEHICLE ADMINISTRATORS' AUTONOMOUS VEHICLE BEST PRACTICES WORKING GROUP

Jude Hurin

Jude Hurin discussed the formation, purpose, and activities of the American Association of Motor Vehicle Administrators (AAMVA) Autonomous Vehicle Best Practices Working Group. He described the partnership with NHTSA to fund the working group, the link with industry, and the group's best practices guide. Hurin covered the following topics in his presentation:

• Hurin reported that NHTSA agreed to fund and partner with AAMVA to establish the AAMVA Autonomous Vehicle Best Practices Working Group. The purpose of the 2-year project is to work with jurisdictions, law enforcement, federal agencies, and other stakeholders to gather, organize, and share information on testing and public use of autonomous vehicles with the AAMVA community.

• Hurin described the anticipated activities of the working group, which included conducting research to gain an understanding of autonomous vehicles and emerging technologies, the impact of these vehicles on jurisdictions, and the potential regulatory concerns these technologies and vehicles create. The working group will develop a best practices guideline document for use by NHTSA and states.

• Hurin noted that the working group was coordinating meetings with experts in the automobile, automation, insurance, and legal communities to obtain a better understanding of their roles, concerns, and challenges. He said that the information collected from these meetings would be used in developing the best practices guideline document. Therefore, it was important to address potential concerns with the testing and public use of autonomous vehicles, but not to overregulate the industry. He further suggested that a new approach focusing on partnering between government and industry may be appropriate.

• Hurin described the focus of the three working group subgroups. The driver subgroup is examining driver licensing requirements, driver training and testing for SAE Level 3 and Level 4 operation, training for state examiners, defining operators versus drivers, possible license restrictions and endorsements, and license suspensions and revocations. The vehicle subgroup is focusing on vehicle testing requirements, insurance requirements, consumer registration and title requirements, state reciprocal agreements for testing, and safety requirements for testing vehicles. The law enforcement subgroup is considering traffic laws with Levels 3 and 4, violation codes, crash investigations with Levels 3 and 4, accessing black box autonomous information, road restrictions, and criminal activity.

• Hurin described some of the challenges associated with autonomous vehicles, including how customized driver–user training may be needed at Levels 3 and 4, as a training manual will probably not be sufficient. Other possible challenges included addressing concerns related to liability, insurance, testing standards, and safety.

• According to Hurin, the best practices guideline document will provide states with guidance in developing state policies and regulations concerning the testing and public use of autonomous vehicles. Further, it will provide NHTSA with a better understanding of the challenges motor vehicle and law enforcement agencies may face and possible responses. He stressed that the best practices guideline document will not be a mandate for states, but rather a first step in addressing some of the challenges associated with autonomous vehicles and innovative technologies. He suggested that research is needed to address many of these challenges and unresolved issues.

ETHICAL CONSIDERATIONS FOR VEHICLE AUTOMATION SYSTEMS

Chris Gerdes

Chris Gerdes discussed potential ethical considerations associated with the design and operation of vehicle automation systems. He summarized the results of recent workshops and projects at Stanford University combining engineering and philosophy to help address ethical questions with the deployment of autonomous vehicles. Gerdes covered the following topics in his presentation:

• Gerdes recognized the assistance of Patrick Lin, a philosophy professor from California Polytechnic State University, in organizing workshops at Stanford University focusing on the ethics of autonomous vehicles and research projects examining the societal impacts of autonomous vehicles sponsored by Daimler Benz. Such collaboration provides the opportunity to explore ethical considerations from engineering and philosophy perspectives, which can be useful as philosophers tend to focus on questions while engineers tend to focus on answers. He suggested that bringing these two disciplines together provides the opportunity to ask the right questions and to develop reasonable approaches to addressing ethical issues with automated vehicle systems. He further suggested that researchers are struggling with identifying the right questions to ask.

• Gerdes used a recent article in the *MIT Technology Review* to highlight the importance of asking the right questions. The article, "Why Self-Driving Cars Must Be Programmed to Kill," reviewed research examining the situation of an autonomous vehicle having to decide whether to hit 10 people in the roadway or swerve to miss the 10 people but hitting one person on the sidewalk. He quoted text from the article, which states "before [autonomous vehicles] can become widespread, carmakers must solve an impossible ethical dilemma of algorithmic morality."

• Gerdes suggested that examining ethics and regulations raises interesting questions. These ethical issues include harm versus care, individual autonomy versus authority, and justice versus fairness, all of which fit with topics discussed by other speakers at the conference. He further suggested that ethical questions are more of a process or a way of thinking, and that developing an ethical framework for making programming decisions would be beneficial. He also noted that ethical questions are unbounded. He suggested that the article asked the wrong question; a more appropriate question might be: Why was the vehicle traveling at a high speed toward a group of people to begin with?

• Gerdes noted the work of Shannon Vallor, philosophy professor at Santa Clara University, and John Sullins, philosophy professor at Sonoma State University, which considers ethics as a process and examines the difference between programming ethics or ethically programming. He suggested that one approach is to focus on ethics as a process and to address questions that society considers as ethical. He noted that travel has three general objectives: mobility (an individual wants to go somewhere); legality (he wants to make the trip within the law); and safety (he wants to arrive safely at his destination). Ethical dilemmas emerge when these objectives conflict. Examples of conflict Gerdes cited included crossing a double yellow line to pass an illegally parked vehicle and exceeding the speed limit when merging into traffic.

• Gerdes discussed different ways of resolving ethical dilemmas. One approach, called deontological ethics, is to weigh objectives, such as by establishing a hierarchy of rules. Another approach, called consequentialism, weighs the costs on different objectives. He noted that these two approaches are being used in programming autonomous vehicles. He also noted that moral laws can be modeled analogously to physical laws, which is parallel to the approach suggested by the philosopher Immanuel Kant. He suggested that another approach would be to work to eliminate conflicts in regulations and laws.

• Gerdes suggested there is an ongoing conflict between safety and mobility, with drivers inherently taking some acceptable risks. He noted that autonomous vehicles may also need to take some risks. He raised the question of how to quantify and communicate acceptable risk, a question that has been examined in other fields, including aviation and building codes. Gerdes commented that Mykel Kochenderfer, professor of aeronautics and astronautics at Stanford University, and Noah Goodall, Virginia Center for Transportation Innovation and Research, contributed to the discussion on these topics at the Stanford University workshops.

• Gerdes suggested that making choices among safety conflicts continues to be a key issue and that focusing on why these situations arise was important to their resolution. He indicated that safety conflicts typically result when someone is not following the rules of the road, with bad actions having bad outcomes. If other drivers have acted responsibly, they are typically not considered responsible for the bad actions of others. He suggested that one possible approach would be to define the extent of a vehicle's responsibility. Possible levels of responsibility include avoiding collisions with other road users who are following the traffic laws, and avoiding collisions with road users who are not following the traffic laws when such collisions can be avoided without harm to others. Further, when collisions are unavoidable, the vehicle's responsibility would be to choose a path that can reasonably be expected to reduce harm.

• In conclusion, Gerdes suggested that ethical programming is a core requirement for autonomous vehicles and that harm, fairness, and autonomy are fundamentally ethical issues that engineers should be aware of. He noted that ethical issues have no limits, however, with new hypothetical scenarios continually being developed. The three ways to help bound the problem and to move forward are to eliminate conflicts with the law, to establish a level of reasonable risk, and to define the extent of responsibility for autonomous vehicles.

TRANSPORTATION AS A SYSTEM: GETTING SMARTer ON ENERGY AND MOBILITY

Reuben Sarkar

Reuben Sarkar discussed recent activities at the U.S. Department of Energy (DOE) focusing on CVs and AVs in the broader context of transportation as a mobility system. He described the five DOE research pillars addressing the energy impacts of this broader mobility system and highlighted projects and pilots currently under way. Sarkar covered the following topics in his presentation:

• Sarkar noted that historically the DOE has focused on vehicle-level efficiency. He commented that this focus has considered technology for the maximum efficiency of independent unconnected vehicles, which are ultimately subject to the behaviors and decisions of drivers. He noted that the DOE has recently taken a broader system-level focus, acknowledging a future of connected and automated systems across modes, with the potential to manage some behaviors and decisions. In this way, he suggested that the DOE is exploring untapped transportation system–level efficiencies.

• Sarkar noted that the DOE is interested in the energy implications of connectivity and automation. He described preliminary research conducted by the DOE National Laboratories that indicated a possible 90% reduction in the 2050 baseline energy consumption from CV, AV, and other technologies. He noted, however, that the research also indicated a potential 200% increase in 2050 energy consumption depending on how CVs and AVs affect travel behavior, vehicle miles traveled (VMT), and other factors. He suggested that this vast range of differing energy implications indicated that more research is needed on this topic.

• Sarkar discussed research opportunities associated with examining the potential impacts of CVs and AVs on energy. He noted that the approximately 240 million vehicles in the United States are used only about 4% of the time. Some research suggests there will be fewer vehicles by 2050, and a 25% reduction in the vehicle inventory would result in new value creation of approximately $2 trillion. He suggested that this available resource would likely drive consumption for additional goods and services and could also result in people traveling more. He suggested that just focusing on the number of individual vehicles misses the importance of how people and goods will move in the future and the resulting energy impacts.

• Sarkar discussed the five DOE research pillars addressing the energy impacts of the broader mobility system. The five pillars are connectivity and automation, vehicles and infrastructure, multimodal, urban science, and behavioral and decision science. He described research activities under way and planned in each of these five pillars.

• Related to the first pillar of connectivity and automation, Sarkar noted that the DOE will be examining the energy impacts of CVs and AVs, including using the National Laboratory capabilities in simulation and modeling for complex systems. He noted that available simulation tools would be used to assess not only individual vehicle efficiencies but also efficiencies with mixed fleets of technologies and system-level efficiencies. The goal is to design for the nexus of safety, energy, and mobility with analysis that would help inform technology research and policy considerations.

• In the vehicles and infrastructure pillar, Sarkar reported that the DOE is using available tools and resources to identify locations for fueling and charging infrastructure. He suggested that CVs and AVs may change the existing paradigm, reducing the number of needed charging stations. Therefore, wireless charging and dynamic charging may be appropriate long-term considerations with AVs, CVs, and different ridesharing and carsharing models.

• Sarkar noted that historically the DOE has focused on individual modes, primarily those that have the largest energy impact. The DOE has not typically considered the end-to-end trip efficiencies and the use of different modes for personal transportation and goods movement. He reported that the multimodal research pillar focuses on better understanding the energy impacts from potential mode shifts and multimodal trips as a result of using CVs, AVs, carsharing, and ridesharing. The focus was also on the energy impacts of efficient, seamless multimodal transportation for people and goods.

• Sarkar discussed the DOE research activities in the urban science pillar, which focuses on designing transportation systems that fit within urban environments and creating urban transportation planning tools for cities and metropolitan planning organizations (MPOs). He commented that the level of complexity in planning future transportation systems is increasing dramatically. In addition, he said that providing cities, MPOs, and regional agencies with tools to better estimate future demands and multimodal options will improve the decision-making process.

• In describing the behavioral and decision science pillar, Sarkar noted the importance of considering human behavior and individual decision making in the development of new transportation technologies and mobility options. Research in this pillar will examine how stakeholders—consumers and others along the transportation value chain—interact with the system and how they make decisions on vehicle purchases, technology adoption, and trip and mode planning. He provided his own experience of living in Washington, D.C., and recently giving up the lease on a car. He noted that he now makes instantaneous real-time decisions about work trips and other travel by using his smartphone. With no longer having to pay the vehicle leasing cost or parking fees, he noted that he rides in a vehicle more than when he owned one. As a result, his consumption has increased, which may be the case for other people as well. He also noted that energy efficiency is not typically part of an individual's short-term decision-making process, nor do individuals have the ability to influence the energy efficiency of the modes they use.

• Sarkar reported that the DOE National Laboratories have simulation and modeling tools that can be used in research in the five pillars. He provided a current example of merging the Autonomie model, which addresses independent vehicle efficiency, and the POLARIS model, which focuses on an entire urban area. He indicated that combining these models provides the opportunity to analyze independent vehicle, city-scale, corridor, and national-level multiscale modeling for energy consumption.

• Sarkar described a recent example of a semiautomated truck platooning project cosponsored by the DOE, the National Renewal Energy Lab, Peloton, Intertek, and the Pacific Car and Foundry Company. The project involved equipping two long-haul sleeper cab trucks with modern aerodynamics, Environmental Protection Agency Smart Way tractors, and trailers with wide skirts. The trucks were then equipped with technologies for platooning, including radar, lasers, and stereo cameras for forward object detection; DSRC; V2V communications and driver displays;

and vehicle braking and torque control interface. Tests were run with two vehicle platoons to analyze potential benefits. He noted that energy savings were realized from the reduced drag of the tandem-running trucks and that when the truck spacing was appropriate, both trucks realized energy benefits. If the trucks were not spaced appropriately, however, negative energy impacts resulted. He noted that the second phase of the project is exploring designing trucks to be more efficient when running in tandem.

• In closing, Sarkar described the new Systems and Modeling for Accelerated Research in Transportation (SMART) consortia. He noted that SMART will bring together the National Laboratories, federal agencies, universities, state and local governments, and industry to focus on energy and mobility in the rapidly evolving CV and AV environment. SMART will begin with the National Laboratories, with the intent of linking SMART mobility with broader metropolitan science.

STEERING AROUND THE POTHOLES: INSURANCE AND AUTOMATED DRIVING SYSTEMS

Edward Collins

Edward Collins discussed the possible impacts of CVs, AVs, autonomous vehicles, ride-hailing services, carsharing services, and the sharing economy on vehicle insurance policies, rates, risks, and services. Collins covered the following topics in his presentation:

• Collins discussed the broad spectrum of new technologies and their possible impacts on vehicle insurance. He noted that technology and innovation represent good news for consumers. He suggested that the spectrum includes collision avoidance on one end and fully automated vehicles on the other end. Safety improvements and enhancing the driving experience for consumers may occur along the spectrum. He suggested that legal and technology issues, or potholes, will be encountered with the move toward autonomous vehicles.

• Collins noted that benefits are already being realized from advanced driver-assistance systems including antilock brakes, adding the third center brake light on the back of vehicles, and other technologies that have improved safety. He suggested that with vehicles and people using more gadgets, driver distraction has become a key pothole. He cited increases in traffic fatalities, serious injuries, and VMT during the first half of 2015.

• Collins discussed how different technologies have different impacts on drivers, vehicles, and insurance. For example, automatic braking and collision avoidance systems could greatly improve safety. Crash frequencies might decline, but crash severities might increase due to lighter and more “thin-skinned” vehicles. He noted that even windshields can contain computerized systems today, which partly explains why it costs $1,500 to replace a Mercedes windshield. Bumpers today also offer greater protection, but at a greater cost, with a $1,200 price tag on replacement of a Lexus bumper cover assembly.

• Collins suggested that connected cars and the sharing economy, which represent a further step along the spectrum, are here today and that their use will accelerate in the near future. He indicated that telematics is being used to reward safe drivers. He noted that approximately 6% of Allstate policy holders have signed up for Drivewise®, an app that can be installed in a vehicle to monitor driver performance, with a discount provided for safe driving. He further suggested that technology can enable different types of insurance policies, rates, and discounts.

• According to Collins, ride-hailing services such as Uber are innovations that raise insurance issues for drivers and passengers. He noted that ride-hailing service drivers need commercial insurance when they have their app activated, even when they do not have a rider, and that passengers want assurance that drivers have the proper insurance. He reported that Allstate has worked with state insurance regulators to ensure these drivers have proper insurance.

• Collins suggested that the potential safety benefits from fully automated vehicles appear to be tremendous, with technology use resulting in decreased physical damage and bodily injury. Fully automated vehicles may also significantly reduce the vehicle population, with some industry experts suggesting as much as a 50% reduction. He suggested that carsharing services will require a different insurance model.

• Collins noted that the timeline for full automation is debatable. The Tesla autopilot software, which was rolled out in October 2015, allows automatic steering within highway lane markers, changing lanes, and parallel parking. He commented that dealing with the transition to autonomous vehicles represents a pothole. He noted that the average age of vehicles on the road was 11 years, so for many years mixed fleets will be on the road, and technology will vary significantly from vehicle to vehicle. Insurance companies are examining these new risks, which will need new types of protection and new insurance services.

• Collins noted that new safety and licensing laws are needed with the transition to AVs and autonomous vehicles, reinforcing the importance of the AAMVA's Autonomous Vehicle Working Group. AVs are specifically authorized in Nevada, California, Florida, Michigan, and the District of Columbia. These laws define key terms such as *autonomous vehicle*, *autonomous technology*, and *operator*. The laws either authorize the operation of autonomous vehicles or recognize that autonomous vehicles are not prohibited within the state. Further, the laws provide varying degrees of requirements regarding safety standards for autonomous vehicles. Finally, the legislation requires that a driver license used for autonomous cars meet certain specifications.

• Collins noted that vehicle insurance and motor vehicle laws are regulated at the state level, with insurance companies dealing with all 50 states and the District of Columbia. He suggested that moving toward some consistency among states related to fully automated vehicle laws and insurance would be beneficial. He suggested that new licensing laws will be needed to provide guidelines for testing autonomous vehicles within a state and to provide a liability framework for addressing situations, such as third-party alteration of a vehicle, that would exempt the manufacturer from liability. Laws may also be needed to authorize a specific department, typically the state DMV, to monitor and regulate the use of autonomous vehicles. He also commented that cybersecurity is a major concern that will require antihacking and other security solutions.

• Collins concluded by summarizing some of the factors that may result in modernizing the motor vehicle insurance model. These factors included sharing arrangements that will likely result in fewer vehicles on the road, usage-based insurance becoming more common, and insurance between insurers and car manufacturers or new pooling arrangements coming into use. Another factor was fewer vehicles and reduced driver error leading to fewer accidents, but increased severity due to technological complexity. He suggested that insurance will still be needed to protect against theft, comprehensive damage, and other losses, but eventually there may be less need for liability and collision coverage. He also suggested that vehicle characteristics will become more important factors in underwriting and rating, as will location, weather, road type, and congestion levels. Other possible factors included liability laws shifting from negligence to product liability and modernization in the insurance regulatory system, including underwriting and rating laws. Therefore, ethical considerations may be needed in product design that could have legal ramifications.

• In closing, Collins noted that advancements in vehicle technologies and transportation modernization were leading to modernization in vehicle insurance models. He suggested that with many of the current insurance models dating back to the 1940s, updated approaches to meet the new realities were needed.

Steven Shladover, California Partners for Advanced Transportation Technology, presided at this session.

PLENARY SESSION 2

Infrastructure Design and Operations

Carla Bailo, *Ohio State University*
Jim Barbaresso, *HNTB Corporation*
Steve Lockwood, *Steve Lockwood, LLC*
John Maddox, *Mobility Transformation Center, University of Michigan*

OHIO SMART MOBILITY INITIATIVE

Carla Bailo

Carla Bailo discussed the Ohio Smart Mobility Initiative. She highlighted the different transportation centers at Ohio State University (OSU), the seven pillars of the Ohio Smart Mobility Initiative, and the OSU Smooth project. Bailo covered the following topics in her presentation:

• The Center for Automotive Research in OSU's College of Engineering conducts research focusing on fuel economy, ITS, safety, and sustainable mobility. The Control and Intelligent Transportation Research Laboratory conducts basic research and has testing, validation, and demonstration capabilities. The Crash Imminent Safety UTC focuses on the human–mechanical interface in the final seconds before vehicle collisions. The Transportation Research Center, Inc., is an independent automotive proving ground that provides research and development, as well as compliance and certification testing of vehicles and components. The 4,500-acre facility is located approximately 30 miles from the OSU campus in Columbus.

• According to Bailo, the Smart Mobility Initiative focuses on the development of smart mobility and smart city technologies that will have major impacts on the state's transportation industry and drive significant job growth. She noted that OSU leads a team that includes the Transportation Research Center, the city of Columbus, and local governments. The Smart Mobility Initiative focuses on workforce development, technology demonstrations, and commercialization programs.

• Bailo described the seven pillars of the Ohio Smart Mobility Initiative. These pillars include technologies to improve safety; smart infrastructure; data analytics and cybersecurity; energy savings from autonomous applications; elderly and disabled mobility enhancements; and food safety, security, and delivery. The seventh pillar focuses on artificial intelligence and ethics, with workforce development an important component of the initiative. OSU is leading the workforce development component to prepare students in engineering, city and regional planning, public policy, economics, and other disciplines for "smart mobility" careers. She noted that ensuring jobs exist in Ohio to match student career aspirations is an important element of the initiative. The workforce development activities include programs at the OSU campus in Columbus and at regional campuses. They also include partnerships with Wright State University and Ohio University. Carnegie Mellon University in Pennsylvania and the University of Michigan are anticipated partners.

• Bailo outlined some of the expected outcomes from the initiative, which included improving transportation efficiency and sustainability through more efficient roadway use, "right sizing" the means of transportation, reducing aggregate fuel consumption, and minimizing air pollution. The initiative is also expected to support a more sustainable economy through the efficient movement of goods and reduced transport costs, as well as promoting carsharing efficiency. Job creation is a further anticipated benefit with new markets for Ohio smart mobility technology industries, better infrastructure management, and smart vehicle management and programming.

• Bailo described the US-33 corridor element of the initiative, which expands the intelligent cities concept from Columbus through East Liberty. The corridor project expands on the Transportation Research Center capabilities by providing on-road testing. She noted that the initiative builds on Columbus' intelligent city concept and supports technology companies in the area. She suggested that the concept could also be expanded to the Midwest region in the future, including Pennsylvania, Michigan, and Indiana.

• Bailo presented a short video of the OSU Smooth project, which is developing and testing AV technologies on the Columbus campus. The use of a driverless electric wheelchair-scooter, which picks up a student and takes him to a bus stop, and a self-driving golf cart were highlighted in the video.

• In closing, Bailo presented the following ideas for future research:

- She suggested that taking a broader view and examining how autonomous vehicles can improve society and people's lives would be beneficial, as would focusing on holistic research that is systems based.
- She also suggested challenging typical research by taking a broad scope and a multidisciplinary approach as well as ensuring more collaboration between academic institutions to capitalize on expertise and to keep up with the speed of technologies.
- She noted that examining public policy issues that must be addressed to implement different technologies and considering establishing standards were other research ideas.

INFRASTRUCTURE DEPLOYMENT CONSIDERATIONS FOR CONNECTED AUTOMATION

Jim Barbaresso

Jim Barbaresso discussed public agency transportation infrastructure considerations for connected automation. He described the role connected automation could play in reducing traffic fatalities, potential public agency needs and concerns, and deployment approaches. Barbaresso covered the following topics in his presentation:

- Barbaresso noted that traffic crashes continue to be a major concern in the United States and throughout the world. Over the next 30 years 1 million people could die in traffic crashes in this country, with almost 40 million fatalities globally. He commented that traffic crashes are the number one cause of death among young people and the fifth leading cause of death overall in developing nations. He suggested that connected automation will help reduce traffic crashes and fatalities.
- Barbaresso pointed out that the basic elements of automobiles have not changed much since the introduction of the Model T in 1908. He noted that seat belts were required 60 years later in 1968, which was also the year with 53,000 traffic fatalities in the United States, the highest recorded annual number. He reported that fatalities have been reduced since 1968 through a combination of vehicle design, roadside safety treatments, and education. Describing the current situation, he suggested there appears to be a race to see who can come out with the first market-ready, fully automated and connected vehicle.
- Barbaresso discussed some of the potential impacts on public agencies and the transportation infrastructure from the deployment of CVs and AVs. He highlighted the results of a survey of state departments of transportation (DOTs) involved in AV-CV projects and a national America THINKS survey of drivers conducted by HNTB. He noted that safety benefits from connected and automated vehicle technology deployment were ranked first by both groups and that drivers were interested in when the safety benefits would begin to be realized.
- Barbaresso indicated that public agencies reported an interest in obtaining vehicle probe data from CVs to improve system performance. Uses of CV probe data suggested by public agency personnel included traffic signal control strategies, corridor management, active traffic management, and weather and event management. Agency personnel also noted that archived probe data would be useful for planning purposes.
- Barbaresso reviewed the technical concerns identified by public agency staff. One concern was the maturity of different technologies. Questions were raised about the street-readiness of CV and AV technologies. Barbaresso commented that transportation agencies were used to working with traffic control equipment with

mature standards that have been applied in common practice for decades, which is not the case with DSRC technology. He also noted that respondents voiced concerns that rapidly advancing technologies would continue to be disruptive and that the deployment time frame was long enough to suggest that more robust advanced technologies may emerge, raising questions about technical obsolescence.

• Barbaresso reported that technical challenges identified by public agency personnel included interoperability and standards, implementation of specific applications, and applications support. Data management, data privacy, communications, and network management represented other technical challenges. Security management and local network security were also identified as technical challenges by public agency staff.

• Barbaresso reviewed the six major institutional challenges mentioned most frequently by public agency staff. The institutional challenges included funding shortfalls that affect deployment, the lack of staff with the necessary technical skills, and the lack of benefit and cost information to support deployment decisions. Other institutional challenges included not knowing the plans of vehicle manufacturers and technology companies, the lack of information to build a business case for deployment, and data access, ownership, and support issues.

• Barbaresso suggested that some agencies are responding to these challenges by preparing for an AV-CV future, while others are taking a more cautious approach. He noted that vehicle connectivity and automation are enabling carsharing and mobility along with on-demand services, which are expanding rapidly in many areas. With vehicles parked 95% of the time, he also suggested that connected automation had the potential to flip that equation; for example, an individual could use one vehicle for their commute trip, use another vehicle to deliver their aging parents to the doctor, and use still another vehicle to take their children to soccer practice. Further, parking needs would be greatly reduced and parking lots could provide space for parks, housing, or other higher-use facilities. Additionally, he suggested that on-street parking could be transformed into pedestrian or bicycle facilities, with cities becoming greener, more walkable, and more livable.

• Barbaresso discussed possible transitions to a connected automated future. He suggested that one approach is to think about managed lanes in a new context. For example, if 20% to 25% of the vehicle fleet is automated, it might be beneficial to dedicate a lane to their use. The number of automated vehicle lanes could be increased as the fleet turns over. He suggested another approach would be to focus on purpose-built automation. Intermodal facilities, first and last mile freight opportunities, residential community and campus applications, and highway maintenance operations represent examples of purpose or situational scenarios.

• Barbaresso described other possible impacts from connected automation. For example, traffic signals and traffic signs may no longer be needed. Tolling and road use charges may change, and there may be seamless travel between roads and modes.

• Barbaresso suggested that if vehicles no longer crash, it may be possible to gain capacity on existing highways by reducing the separation between vehicles, increasing and harmonizing speeds, and decreasing lane widths. He noted that lane capacity increases of up to 300% have been suggested. He further suggested that clear zones would not be needed, with the land put to more productive use or used for other modes. Right-of-way costs and the need for new highways could be reduced. Additionally, eliminating crashes would reduce fatality rates and improve the quality of life for everyone. Connected and automated technologies could provide mobility to blind and disabled individuals. These technologies could also enable individuals to be more productive while traveling. Although they may result in personal cost savings, these technologies may also disrupt the automotive, taxi, and insurance industries.

• Barbaresso described some of the approaches transportation agencies could consider in preparing for the uncertain future. First, he suggested that being systematic is important. Beginning with needs-driven pilot deployments presents one systematic approach. He also suggested developing a strategic systems engineering approach that lays out an action plan for the next 5 years, which represents a reasonable planning horizon in a dynamic environment. He noted that the systems engineering approach addresses stakeholder needs and potential risks. Second, he suggested that transportation agencies ready their resources, including improving signs and markings, developing robust communication systems, strengthening data management capabilities, and strengthening staff technical capabilities. Evaluating planning, policies, and organizational impacts represents another suggested approach. Barbaresso also stressed the importance of working with industry to understand and potentially influence the direction of change and educating internal and external stakeholders.

• Barbaresso highlighted the following five research questions for further discussion during the breakout session:

  -How can we assess investment decisions regarding these emerging technologies and applications without experiential data?
  - At what point should public agencies begin to invest in infrastructure changes?
  - How do we amend traffic models and forecasting tools for an uncertain future?
  - What are the unaddressed data needs of public agencies?
  - What new highway design standards will be required, and when?

• In closing, Barbaresso suggested that connected automation was a game-changer. He noted that the integration of CV and AV technologies into the existing operational environment would be challenging and disruptive to current paradigms. As a result, he noted that engineering and operational concepts, performance measures, algorithms, the transportation workforce, design standards, traffic control systems, and policies will be transformed.

STATE DEPARTMENT OF TRANSPORTATION READINESS FOR CONNECTED VEHICLE SYSTEM SUPPORT

Steve Lockwood

Steve Lockwood discussed the roles and readiness requirements of state DOTs in providing the infrastructure needed to support CVs. He identified the short-term and long-term processes, institutional and technical capabilities, and infrastructure necessary for CV deployment and operation. Lockwood covered the following topics in his presentation:

- Lockwood noted that CV systems introduce public-sector infrastructure owners and operators into the service provision loop. Infrastructure elements needed for V2I include roadside sensors and communication systems, as well as transportation management centers, data processing, and data analytics. He suggested that public agencies may face challenges in providing, operating, and maintaining these systems, especially given the uncertainty of the path and timing of CV deployment.
- Lockwood identified some of the critical capabilities transportation agencies should possess to support CV systems based on experience with advanced ITS and transportation systems management and operation (TSM&O), which provide a template for the required capabilities and a point of departure for current capabilities. He suggested that this comparison identified a need for a clear policy commitment and organization adjustments, technical education and training, and new forms of public–private partnerships to support CV systems.
- Lockwood summarized recent projects from the second Strategic Highway Research Program (SHRP 2) and FHWA that examined the specific capabilities needed at transportation agencies for new systems implementation. The essential preconditions to effective agency deployment and utilization of new technology and systems were identified in the SHRP 2 project, and the average and most effective state programs were compared. He noted that self-evaluation workshops were conducted with 45 states using the capability maturity model, which is commonly used in the information technology industry.
- Lockwood described Figure 2, which highlights the six capability dimensions of the capability maturity model self-assessment framework that research determined to be critical. He noted that the pillars are process oriented. The business processes pillar focuses on planning, programming, and budgeting. The systems and technology pillar includes the use of systems engineering, systems architecture standards, interoperability, and standardization. The performance measurement pillar addresses the definition of measures, data acquisition, and utilization. The three foundation blocks focus on institutional dimensions. The culture block includes technical understanding, leadership, outreach, and program legal authority. The organization and staffing block addresses programmatic status, organizational structure, staff

FIGURE 2 Dimensions of agency capability to support development of new systems. (Source: U.S. Department of Transportation.)

development, and recruitment and retention. The collaboration block addresses relationships with public safety agencies, local governments, MPOs, and the private sector.

• Lockwood reported that for each of the six dimensions of capability, the self-assessment uses four criteria-based levels of capability maturity that indicate the direction of managed changes required to improve TSM&O effectiveness. The four levels are defined as follows:

- Level 1, Performed. Activities and relationships are largely ad hoc, informal, and champion driven, substantially outside the mainstream of other DOT activities.
- Level 2, Managed. Basic strategy applications are understood; key processes' support requirements are identified and key technology and core capacities are under development, but there is limited internal accountability and uneven alignment with external partners.
- Level 3, Integrated. Standardized strategy applications are implemented in priority contexts and managed for performance; TSM&O technical and business processes are developed, documented, and integrated into the DOT, and partnerships are aligned.

- Level 4, Optimizing. TSM&O as a full, sustainable core DOT program priority is established on the basis of continuous improvement with top-level management status and formal partnerships.

• Lockwood noted that most state DOTs completing the self-assessment fell within the Level 1 (Performed) or Level 2 (Managed) categories. These results indicated that most agencies understand the key issues in the Level 2 dimension and are in the process of developing a more managed approach to dealing with them. Further, he reported that some agencies are beginning to move TSM&O dimensions to Level 3 (Integrated).

• Lockwood described examples of AV-CV requirements for each of the six capability dimensions. Examples of business process capabilities included making the business case, establishing policy priorities, infrastructure planning, and funding. Examples of systems and technology capabilities included examining the risks associated with rapidly evolving technology, interoperability and standardization, relationships with original equipment manufacturers (OEMs), and technology acquisition and updating. Performance measurement capabilities included performance measures, data acquisition and analytics, big data management, and user information dissemination. Examples of culture capabilities included commitment to technology for safety and mobility, support of real-time systems operations, and education and marketing. Effective organizational structure, specific technical capabilities, and staff recruitment and retention were examples of organization and staffing capabilities. Collaboration capability examples included interjurisdictional collaboration and interoperability, deployment, and operations. He described examples of the current state of the practice with many of these capabilities, noting areas for improvements needed to achieve the AV-CV vision. He noted that states can use the tool developed to assess AV-CV readiness.

• Lockwood suggested that depending on institutional constraints, state DOTs can focus on strategies to improve key technical, managerial, and financial agency capabilities or to develop appropriate outsourcing business models. He noted that new business models will need to be developed to address investment, risk, and reward sharing with private partners. Further, new procurement and contracting methods will probably be needed. Models focusing on resource sharing, franchising, chartering, and privatizing may be appropriate for consideration.

• In concluding, Lockwood suggested there is a good understanding of the capabilities that are needed in transportation agencies to accommodate AV-CV deployment. Continuing to examine those capabilities that are critical to maintain within transportation agencies and those that can be outsourced is needed, however, as is developing appropriate business models for outsourcing. He further suggested that all groups—professional organizations, federal and state agencies, universities, and private-sector groups—are needed to address these issues.

UNIVERSITY OF MICHIGAN MOBILITY TRANSFORMATION CENTER

John Maddox

John Maddox discussed the University of Michigan Mobility Transformation Center (MTC). He described the focus of MTC, its partners, its primary research areas, and the three pillars of the program. Maddox covered the following topics in his presentation:

- According to Maddox, MTC is a public–private research and development partnership that will lead a revolution in mobility and establish the foundations for a commercially viable ecosystem of CVs and AVs. The focus is on prototyping an entire system of connected and automated transportation on the streets of southeast Michigan through 2021. He reported MTC represents an initial investment of approximately $100 million over 8 years, with $25 million provided by the University of Michigan.
- The University of Michigan is leading MTC, but it has numerous partners from industry, government, and academia. Industry partners include the automobile companies (or OEMs), component and system suppliers, telecommunications companies, and firms specializing in big data management. Other partners come from the freight industry, insurance companies, and businesses specializing in traffic control systems, payment systems, and smart parking technologies. Government partners include the U.S. DOT, the Michigan Department of Transportation (Michigan DOT), the U.S. Department of Energy, the Automotive Office of the Michigan Economic Development Council, and the City of Ann Arbor. Academic partners are the Texas A&M Transportation Institute, Carnegie Mellon University, and the University of Maryland Center for Advanced Transportation Technology Laboratory. Numerous affiliate members broaden the participating ecosystem.
- Maddox reviewed the internal partners at the University of Michigan, which include the College of Engineering, the Medical School, the College of Architecture and Urban Planning, and the School of Business. Internal partners also include the School of Public Policy, the Law School, the School of Information, the Energy Institute, and the University of Michigan Transportation Research Institute. He noted that the ability to draw on diverse resources and expertise throughout the university was a benefit.
- Maddox highlighted the priority MTC research areas, which include connectivity (vehicle to everything, or "V2X"), automation, cybersecurity, standards, consumer acceptance, legal issues, and business models. Second-level research areas are ITS interoperability, data analytics, human factors, energy use and emissions, regulatory issues, and compliance. Public policy, urban planning, infrastructure

design, social implications, payment methods, and congestion management represent other secondary research topics.

• Maddox stressed that deployments are necessary to address the research areas in a comprehensive and accelerated manner. MTC was envisioned to be a living laboratory for public and private projects. He described the MTC platforms for innovation, which center on three pillar programs operated in collaboration with Michigan DOT. The three pillars are the Ann Arbor Connected Vehicle Test Environment, the Southeast Michigan Connected Vehicle Deployment, and the Ann Arbor Automated Vehicle Field Operational Test (FOT).

• Maddox described the different elements of the Ann Arbor Connected Vehicle Test Environment, which will include up to 9,000 vehicles, 12 freeway sites, and 60 intersections. Over-the-air security, a backhaul communication network, and back-end data storage represent other elements. Testing V2I and vehicle-to-pedestrian functions is a key focus of the project.

• The second pillar described by Maddox was the Southeast Michigan Connected Vehicle Deployment, which will include up to 20,000 vehicles over the next 3 to 4 years. He noted that it builds on the Michigan DOT smart corridors and includes the Michigan CV Pilot project. With OEM participation, the project includes product development and deployment.

• Maddox described the elements of the Ann Arbor Automated Vehicle FOT, which is the third pillar. It includes 2,000 connected and automated vehicles, including Level 4 AVs. The project includes personal vehicles, public transit buses, trucks, bicycles, and pedestrians. It covers 27 square miles of densely instrumented infrastructure in Ann Arbor. In addition to the University campus, there are two major hospitals approximately one-half mile apart and an assisted living facility.

• Maddox discussed Mcity, which is part of the Ann Arbor Automated Vehicle FOT. He noted that Mcity provides a safe, repeatable, off-roadway test environment for AVs. It accommodates technology research, development, testing, and teaching. He said that the $6.5 million project was split equally between Michigan DOT and the university. Construction of Mcity began in July 2014, and the grand opening was held on July 20, 2015. He noted that the testing facilities at Mcity were currently fully booked.

• Maddox provided his perspective on some of the barriers to the development of CVs. One barrier he suggested was the slow development of a critical mass of CVs and supporting infrastructure. He suggested that return-on-investment data were needed to promote infrastructure development. A second barrier was customer acceptance and understanding, including developing the value proposition for consumers and addressing loss of privacy fears. Other barriers include the need for a national strategy for deployment, funding mechanisms to support deployment, cybersecurity of CVs and infrastructure, and spectrum uncertainties.

• Maddox outlined the following priority research questions that may assist with CV deployment:

- What is the optimum usage of the allocated DSRC spectrum?
- What are the design and functional requirements of a high-quality vehicle retrofit device?
- What are the potential business and deployment models for infrastructure?
  1. Will V2I investment pay back?
  2. Are there workable private business models for V2I?
  3. How much should agencies set aside for operation and maintenance?
  4. How do payment systems fit in with new V2I business models?
- How can we ensure that vulnerable road users benefit from connected technology?
- What data handling tools are needed for aggregated data?
- How can we use early deployments to assess strengths and weaknesses of security credential management systems?
- Can we quantify benefits of V2I energy apps through simulation and demonstration?

• Maddox discussed some of the critical barriers to automation and related research needs. Examples of barriers include AV operation in mixed traffic, AV capabilities in bad weather, and transitioning to vehicle control with partial automation. Other barriers he discussed were the need for standardized technology assessments and validation for safe operation. Customer acceptance and understanding, cybersecurity of AVs, and legal, liability, and insurance uncertainties were still other potential barriers. He identified the following research questions that may address these barriers:

- How do AVs perform in bad weather?
- How will AVs be tested, assessed, and validated for safe operation?
  1. How much is enough when testing for reliability?
  2. Is standardization of testing methods and criteria required?
  3. How will track testing be integrated with on-road driving?
  4. How can simulation be leveraged with all of the above issues to assess readiness?
- How will AVs interact with human-driven vehicles?
- Should AVs behave like humans in critical or ethical situations?
- How will insurance, liability, and licensing be implemented to create maximum benefit?
- What can be done to speed public acceptance of AVs?
- Can we determine a benefit to nonconnected and/or nonautomated vehicles in the environment?
- How do connected AVs interact with legacy vehicles and existing infrastructure and systems?
- What specific value does vehicle-to-everything connectivity bring to an AV?
- What are the roles for the built infrastructure?
- What are the roles for data and mapping infrastructure?

• Maddox also identified the following crosscutting research questions related to data collection, analytics, and societal impacts:

- What data should be stored on CVs-AVs to aid in determination of the root cause of crashes and malfunctions?
- What existing data sets could be leveraged with new CV-AV data sets?
- What deployment data should be collected, and what are their uses?
- How can data drive entrepreneurship and new business models?
- What are the impacts of CVs-AVs on energy and health?

• Maddox reviewed some of the initial research projects being conducted by MTC, including projects involving cybersecurity issues, regulatory approaches, consumer acceptance, and driver behavior with different operational scenarios.

• In closing, Maddox suggested the following questions for discussion in the breakout groups:

- Should we monetize shared DSRC spectrum to pay for V2I investment?
- Can or should the United States catch up to Europe on funding for AV FOTs?
- How do we ensure that CVs-AVs really deliver societal benefits related to safety, mobility and congestion, and energy savings?
- How do we avoid a patchwork of state AV requirements, without NHTSA regulating prematurely?
- Do we need a national strategy on CV-AV deployment?

Patrick Szary, Rutgers University, presided at this session.

PLENARY SESSION 3

Planning

Johanna Zmud, *Texas A&M Transportation Institute*
Matt Smith, *Michigan Department of Transportation*
Ram Pendyala, *Georgia Institute of Technology*
Jane Lappin, *Office of the Assistant Secretary for Research and Technology, U.S. Department of Transportation*

AUTOMATED AND CONNECTED VEHICLE DEPLOYMENTS: IMPLICATIONS FOR STATE AND LOCAL TRANSPORTATION AGENCIES

Johanna Zmud

Johanna Zmud discussed a recent research study conducted by the Texas A&M Transportation Institute (TTI) that examined the implications of AV and CV deployment for state and local transportation agencies. She discussed the definitions of AV and CV, described how the deployment scenarios were used in the study, and summarized the reactions to those scenarios from personnel with public agencies and the private sector. She highlighted potential changes for organizations resulting from AV and CV deployment and policy and planning actions to assist in addressing potential challenges. Zmud covered the following topics in her presentation:

• Zmud discussed the definitions of AV and CV used in the project, which she said were important in developing the deployment scenarios and in establishing a common understanding for the interviews. The AV description focused on vehicles equipped with internal sensors, cameras, GPS, and advanced software. She noted that the NHTSA levels of automation were used in the definition and that CV technology was not required with the AV alternative. She further noted that the AV description included personal vehicles, public transportation, and interurban and urban freight. The CV description focused on DSRC, Wi-Fi, and cellular technologies. Data gathering and information exchange would occur through V2I and V2V. The CV applications included E-payment transactions, signal phase and timing information, V2V safety messages, and probe data. Zmud highlighted another TTI research project being conducted for the Texas Department of Transportation (Texas DOT) as an example of near-term applications. The project is examining the use of AV and CV technologies to reduce collisions involving buses, bicycles, and pedestrians and to improve bike racks-on-buses safety. Katie Turnbull of TTI is the principal investigator on the project.

• Zmud noted that state and local agency personnel voiced different perspectives on AV and CV technologies during the interviews. Many state and local staff reported feeling sidelined by AV deployments, with OEMs and the private sector driving the process. They also expressed concerns over disruptive technologies and not knowing what was expected from their agencies. Zmud reported that agency staff expressed uncertainty and confusion related to their roles and responsibilities with AVs operating in mixed traffic with dynamic conditions, traffic signals, signage, and striping.

• Related to CV deployment, Zmud reported that state and local agency representatives felt that OEMs and the private sector would implement V2V. She said uncertainty was expressed concerning V2I implementation, especially the business model for deployment, training for staff, the costs associated with implementation, ongoing technical support, and maintaining and updating databases and detailed mapping. She noted that even with these concerns, state and local personnel expressed excitement about the data that will be available from CV applications. Data ownership and data sharing were raised as concerns that would need to be addressed, however.

• Zmud explained the scenario-based road mapping process used in the project. Two AV-CV deployment path scenarios were developed based on a literature review and workshops with experts. The scenarios were used in interviews with state, MPO, city, and toll authority staff to identify possible implications and impacts. The information from the literature review, the expert workshops, and the interviews was used to develop a strategic road map that agencies could begin to use now to prepare for the future.

• Zmud explained the use of the scenario approach, which included the development of two distinct narratives about the future. The scenarios represented two plausible extremes that allowed participants to focus on the potential impacts of two very different situations. They also provided the limits (or boundaries) within which a more realistic future might emerge.

• Zmud noted that a systems approach focusing on the four influence areas of society, technology, economy, and policy was also used in developing the scenarios. The societal influence included market demand, consumer acceptance, automobile ownership, operating environments, and data privacy. The technology influence factors were driver–vehicle interface, cybersecurity, sensor technology, and vehicle decision making under uncertainty. The economic factors were consumer buying power, sectoral disruption, cost of technology, and infrastructure investment. Policy factors focused on market-driven or prescriptive policies, V2V mandates, and liability issues. She commented that the factors in the scenarios were intertwined.

• Zmud described the basic characteristics of the two scenarios. The revolutionary scenario began with a V2V mandate in 2016 and assumed there would be a significant number of self-driving vehicles in operation by 2025. In this scenario the OEMs and technology companies would undertake significant research and development activities, bringing disruptive technologies to market very quickly. The policy framework was supportive of rapid deployment.

• Zmud described the evolutionary scenario, which included the same V2V mandate in 2016, but in which a critical mass of self-driving vehicles would not be reached until 2050. She said that numerous technology and regulatory issues would cause friction and delay deployment.

• Zmud discussed the different drivers for the two scenarios. The triggers for the revolutionary scenario were disruptive innovation and consumer demand, compared to precautionary and partisan policy making and technical issues for the evolutionary scenario. Other drivers for the revolutionary scenario included a strong economy, demand from baby boomers and young adults, and timely support of federal and state legislation. Additional drivers for the evolutionary scenario were a sluggish economy, slower turnover in vehicle fleets, price, negative media, and cautious federal and state legislation.

• Zmud summarized results from interviews with 30 transportation professionals from the public and private sectors concerning which scenario they felt was more likely to occur and which scenario they preferred. She noted that a slight majority felt the revolutionary scenario was more likely to occur. Some of the factors she cited influencing this response were consumer interest and the market demand generated by OEMs and technology companies for AVs. The initial deployment suggested by respondents included trucking, shared ride, and package delivery applications. The majority of respondents also reported a preference for the revolutionary scenario. One factor influencing this response was the belief that the private sector would provide the resources needed for deployment. She said further that personnel from state DOTs favored the evolutionary scenario, primarily because it provided more time to develop the enabling infrastructure.

• Zmud summarized the responses to questions on potential changes for organizations based on the two scenarios. Respondents did not report any anticipated changes in the mission of their agency or organization. In terms of responsibilities, participants felt there would be less emphasis on construction, safety, human services, transportation, traditional ITS, and parking management. They suggested there would be more emphasis on maintenance, operations, and big data management and analysis. She noted that some participants raised concerns that their agency did not currently have the needed expertise on big data analytics and management. Participants suggested there would be a larger operations group at their agency and a specific AV-CV section or group.

• Zmud reviewed the responses to questions concerning the policy or planning actions that were being taken or could be taken to prepare for AVs and CVs. Responses included reviewing current legislation and policies that could affect the implementation of AV-CV technologies, designating a specific individual within the organization with AV-CV responsibilities, and participating in the national discussion on AVs and CVs. Other suggestions were establishing working relationships with available resources in the state and the region, communicating with state and local policy makers to familiarize them with and educate them on AV-CV issues, developing a plan for workforce development, and formulating strategies to address the financial challenges of implementation.

• In closing, Zmud suggested the following five research topics for further discussion:

- Developing a business case for V2I;
- Determining the degree to which V2I technology was necessary for AV deployment;
- Monitoring changes in private vehicle ownership and the use of vehicle-on- demand fleets and shared services to identify possible future market developments;
- Examining differences in regulatory issues for AVs and models of private vehicle ownership or vehicle-on-demand fleets; and
- Exploring the role after-market technologies might play in AV deployment.

MICHIGAN DEPARTMENT OF TRANSPORTATION CONNECTED VEHICLE INITIATIVE

Matt Smith

Matt Smith discussed the different CV projects and programs under way in southeast Michigan. He described the role of the Michigan DOT in the projects and their anticipated benefits, current status, and future activities. Smith covered the following topics in his presentation:

• Smith reported that although Michigan had made impressive strides over the past decade in reducing traffic fatalities, there has been a leveling out over the past few years. He suggested that applying new approaches, combined with the ongoing comprehensive campaign of traffic safety engineering, enforcement, and education, was needed. He thought that CVs and AVs could revolutionize automobile travel and reduce crashes, especially those involving driver error, and that there is a role for V2I in making V2V work.

• According to Smith, the success of the Safety Pilot Model Deployment has developed a core area of expertise in CV systems in southeast Michigan. He noted that the intent is to create a sound base for expanding the Safety Pilot Model Deployment into a regional CV deployment. Working in partnership with General Motors, Ford Motor Company, the University of Michigan, the Road Commission for Oakland County, and other partners, Michigan DOT has set a vision for a smart corridor in southeast Michigan. Centered along the freeway and surrounding arterial network in the metropolitan Detroit area, the corridor includes the heart of Michigan's automotive and technology industry. It also links to several other CV deployments, including the U.S. DOT's test bed in Oakland County, a deployment in the City of Detroit to support the 2014 ITS World Congress, and the Safety Pilot Model Deployment/Ann Arbor Test Environment in Ann Arbor. He noted these efforts represent a multiyear investment, with a vision for a connected region and a connected state.

• Smith described some of the components in the different projects. He noted that the smart corridor focused on deploying V2I on over 120 miles of roadways in the Detroit metropolitan area. The project includes an initial deployment of 17 roadside units to supplement the existing U.S. DOT testbed in Oakland County. Other elements included upgrading 80 roadside DSRC units installed in 2005 and nine signalized intersections with controllers capable of transmitting signal phase and timing messages.

• Smith described four key components needed for V2I. The first component was the transportation infrastructure. He noted that a key function of state DOTs was developing and maintaining roads, bridges, pavement, traffic signals, and other infrastructure elements. The second component Smith highlighted was vehicles. Although state DOTs own and operate a variety of vehicles, most do not have expertise in the technology components of vehicles. The third component was the back-end data storage and processing system. He noted that the fourth component, the communication system, links all the V2I components and suggested that it was probably one of the most expensive items in V2I.

• Smith said that CV systems generate lots of data, with a single CV generating literally thousands of data points every minute. He described the fixed and mobile data systems that feed the Michigan DOT data use analysis and processing (DUAP) system and its applications. The DUAP research project focuses on using CV data and other mobile observations, in conjunction with traditional Michigan DOT data sets, to populate a series of applications addressing the safety, mobility, and asset management goals of Michigan DOT. He reported that the initial set of DUAP applications was selected through a departmentwide needs analysis. One of the applications focuses on using real-time data and data analytics to determine the condition of Michigan DOT assets.

• Smith described the DUAP goals and objectives. The three goals of the system are to use CV and AV data, to increase data sharing, and to support performance management. The objectives include developing frameworks for application development and identifying, prioritizing, and developing applications. Other objectives focus on integrating existing Michigan DOT data and providing interfacing applications. He noted that the focus was on developing possible data applications related to the five key Michigan DOT roles of planning and asset management, design, construction, maintenance, and operation. Approximately 124 potential applications for using CV data were identified in these five areas. He described the screening process used to prioritize the possible applications, which examined public benefits, agency benefits, industry needs and use, application readiness, and data availability. The five applications identified as the top priorities were red light violation warning, work zone warning and management, border wait time, road weather management, and pavement condition.

• According to Smith, the red light violation warning application will communicate with vehicles approaching an intersection, providing a warning that, if a vehicle's current speed is maintained, the vehicle will run a red light. Future functionality of this application could warn vehicles on the cross street of a pending vehicle entering the intersection on a red light. He noted that Michigan DOT is supporting the U.S. DOT and the Collision Avoidance Metrics Partnership.

• Smith said that the work zone warning and management application will provide real-time information to drivers on the location of lane closures due to road construction and maintenance activities. Information on additional related hazards, such as queuing due to lane closures and slow or stopped vehicles within the work zone, is also expected to be provided. He reported that an initial test should be in operation in the spring of 2016.

• Smith said that Michigan DOT is participating in the Weather Responsive Traveler Information (WxTINFO) project, which brings together near-time environmental and weather-related data collected from both fixed and mobile data sources and provides this information directly to travelers. The DUAP system will perform the back-end data processing to automatically generate location-specific, real-time weather information and provide it to motorists via roadside dynamic message signs and the MiDrive traveler information website. He thought that CV data could further enhance the system.

• Smith described the border wait time system on the Blue Water Bridge International Crossing to Canada. Michigan DOT is partnering with the Ontario Ministry of Transport to implement the border wait time system for travelers and truck operators crossing this border between Michigan and Canada. A combination of Bluetooth and fiberoptic technologies is being used, with information disseminated to motorists and commercial vehicle operators through roadside dynamic message signs, the MiDrive traveler information website, and smartphone applications.

• According to Smith, the pavement condition application uses a suite of off-the-shelf sensors and Michigan DOT vehicles to measure and detect pavement conditions. The application supports maintenance (performance-based maintenance and pavement defect detection), design (pavement warranties and pavement life-cycle analysis), and asset management (surface conditions and ride quality).

• Smith described the use of Michigan DOT vehicles as CVs. Working with partners, Michigan DOT has developed a suite of off-the-shelf components for use in these vehicles. He reported that five Michigan DOT vehicles have been instrumented to date, with another 15 vehicles programmed and 80 more planned for the future.

• In conclusion, Smith provided some suggestions to help prepare state DOTs for a CV future:

- He noted the importance of considering the application and deployment needs of an agency or an area. Focusing on key needs is important, rather than just deploying technology because it is available. He commented that identifying and addressing the most important problems should be the focus.
- Smith stressed the importance of partnering. Transportation agencies cannot do it alone; the system only works with the participation and cooperation of vehicle manufacturers, suppliers, technology companies, and communications providers.
- He noted the need to expand the skill sets of workforces at transportation agencies. He highlighted the importance of expanding from a civil engineering focus, as different skill sets are needed for designing, operating, and maintaining highly complex CV systems. He commented that developing and recruiting staff with skills in communications technology, network design, application development, and other related fields was important.
- He also noted the need to focus on developing new business models, mainstreaming technology, and leveraging other opportunities.

UNDERSTANDING THE POTENTIAL IMPACTS OF CONNECTED AND AUTOMATED VEHICLES ON ACTIVITY-TRAVEL BEHAVIOR: IMPLICATIONS FOR TRANSPORT MODELING

Ram Pendyala

Ram Pendyala discussed the impacts of CVs and AVs on travel behavior modeling, transportation planning, and travel forecasting models. He addressed future mobility options, technology adoption in the marketplace, and vehicle ownership, use, and evolution issues. He also discussed behavioral modeling issues and challenges and suggested possible enhancements to transport models to address these concerns. He acknowledged the assistance of his coauthors, Chandra R. Bhat of the University of Texas at Austin and Patricia L. Mokhtarian of the Georgia Institute of Technology, in developing the presentation. Pendyala covered the following topics in his presentation:

• Pendyala described future mobility options associated with different levels of connected, automated, and autonomous vehicles. He noted the different V2V and V2I configurations, the various degrees of automation, and the truly driverless autonomous vehicles. Pendyala discussed the emergence of alternative mobility options, including private station-based carsharing, peer-to-peer carsharing, on-demand services, and ridesharing services. He suggested that the combination of different types of disruptive technology and vehicle automation may lead to a new age of accessible on-demand autonomous transportation.

• Pendyala discussed factors that may need to be incorporated into the transportation planning and travel forecasting processes based on CV and AV deployment. These factors included no crashes due to human error, rare crashes due to technology failure, the elimination of traffic congestion, improvements in use of infrastructure in time and space, and decreases in travel costs. Other factors were decreases in the energy and environmental footprint of travel, reduced trip costs, reductions in the need for parking infrastructure, and enhanced speed and decreased cost of goods movement.

• Pendyala described forces that may delay or accelerate the adoption of CV and AV technology in the marketplace, including legislation related to regulations, taxation, and data sharing. Other forces included social attitudes associated with safety and willingness to share, technology development, privacy and security, and economic forces.

• Pendyala discussed the pace of technology adoption over the past century. He suggested that based on cell phone, tablet, Internet, and online social networking site use, the pace of technology adoption seems to be increasing. Numerous factors may be contributing to this acceleration, including higher incomes and a more technology-savvy population. Adoption levels never reach 100%, indicating that there will probably be a need to accommodate mixed traffic conditions for a long time even if the majority of people move to CVs and AVs. He also suggested that the vehicle turnover rate, with the average age of vehicles in the United States at 9.4 years, also indicates a longer period of mixed traffic. For example, the acquisition of alternative fuel vehicles accounts for less than 1% of total vehicle purchases, even with rebates and incentives, special privileges, and promotions.

• Pendyala highlighted the results from a 2014 survey conducted by the University of Michigan Transportation Research Institute that indicated moderate interest in self-driving vehicles and concerns over driving or riding in a vehicle with self-driving technologies. Respondents also did not indicate a willingness to pay extra for self-driving technology. The highest responses to a question on how people would use their time instead of driving were "watching the road even though they were not driving" (35%) and "I would not ride in a self-driving vehicle" (23%). Pendyala suggested that additional surveys of this type were needed to better understand possible adoption rates.

• Pendyala described the rapid adoption of transportation network companies and on-demand mobility services, such as Uber, in many areas. He noted that over the past 15 years, services like Zipcar attracted 1 million users in North America and 1.7 million users globally. Within 5 years, Uber has attracted at least 8 million users globally. Further, he noted that as of January 2015, 160,000 people drove for Uber worldwide. He suggested that city regulations may limit the growth of transportation network company services, and cited the recent unsuccessful attempt by the New York City Council to approve laws capping the number of for-hire cars operating in the city.

• Pendyala noted that vehicle ownership, use, and evolution questions raise behavioral modeling issues and challenges. He described some of the considerations in modeling vehicle ownership and fleet composition, including technology options, bundles, and costs, as well as willingness to share and on-demand mobility services and costs. He discussed the need to identify relevant vehicle types and modal alternatives for modeling purposes, noting that evolving technology may render the identification of alternatives and their attributes challenging. He also noted the need for integrating vehicle fleet composition, usage, and evolution to capture technology penetration time frames for travel forecasting models. He thought that dynamic transaction models would be needed to integrate the capability to play out different services into transportation forecasting models in the future. For example, personal vehicle ownership may become a relic of the past as the use of on-demand mobility services increases.

• Pendyala described recent work conducted using a Korean study on vehicle choices and technology. The Korean study focused on alternative fuel vehicles and emerging vehicle technology options and included a stated preference survey that collected information about participants' choices in a hypothetical situation for different technology options. The options included connectivity, voice command, autonomous driving, wireless Internet, and traffic information applications. He reported that faculty from Georgia Tech and the University of Texas at Austin analyzed the data to develop a willingness-to-pay value for various features. The results indicated that people were more willing to pay for connectivity and wireless Internet than for other technology features. He suggested that additional studies of this type are needed to better understand customer willingness to pay and to match that information to the anticipated technology cost.

• Pendyala noted that to better understand the impact of emerging technologies on VMT, it was important to focus not only on vehicle ownership but on how vehicles will be used. On the one hand, he suggested new technologies may replace a drive-alone trip with a shared mobility service and transit or some other combination, which helps solve transit's first and last mile problem. It may also eliminate a personally owned vehicle. Other outcomes may be more neutral, such as a one-to-one replacement of a trip by a different mode. On the other hand, Pendyala suggested that emerging technologies may result in increased VMT by displacing a transit trip or replacing a carpool trip with multiple single-rider AV trips, thus making travel easier and cheaper. Further, cruising "empty" on-demand vehicles may increase VMT. He suggested that all these potential competing outcomes and impacts need to be taken into account in transportation forecasting models.

• Pendyala suggested that examining potential impacts of AVs on transit use was also important. AVs could complement transit by addressing the first- and last-mile problem, negatively affect transit by stealing market share, or completely redefine transit. He also noted that as a result of AVs or on-demand vehicles, parents may be able to reallocate their time spent in shuttling their children to activities and instead make other trips, get a job, work longer hours, or stay at home.

• Other modeling needs and issues identified by Pendyala included factors influencing the adoption and use of AVs and on-demand mobility services, including age, education, lifestyle, inability to drive, and technology interests. He suggested that mode choice models will need to be expanded to accommodate more complex options and a greater variety of services. Changes may occur in ridesharing and chauffeuring patterns, and if on-demand mobility services are not reliable, people may continue to own a vehicle as a backup.

• Pendyala outlined a possible typology of choices. Long-term choices he identified included lifestyle, residential and work locations, and business location choices. Medium-term choices were vehicle ownership and usual mode of use choices and household-level choices. Short-term choices included daily mobility choices and activity-travel patterns, and instantaneous choices focused on decisions made en route. He suggested that AVs and on-demand services may influence choices at all these levels.

• Pendyala identified key transport model enhancements that may be needed to address the influence of increasing choices. He suggested that tracking vehicle ownership is no longer enough and that a vehicle-type choice model is needed to identify vehicles used for specific tours and trips. He also noted the need for a vehicle-tracking algorithm to track the availability of each vehicle for any agent in a specific context, and an agent-based mesoscopic and microscopic simulation model to trace vehicles and travelers through time and space. The model would also have to account for empty VMT when unoccupied vehicles are traveling to pick up passengers. Disruptive technologies could be a game-changer for activity generation, with significant induced demand, similar to the impact of aviation on long-distance travel demand. Choice set formation is one key consideration, including vehicle alternatives and their attributes and modal options and their attributes. Features, attributes, and options affect market penetration rates. An enhanced on-demand taxi travel model could be used to account for emerging mobility services, as most current taxi trip models are rudimentary. He further suggested considering all disruptive options, forces, and technologies together in a holistic manner.

• Pendyala discussed recent attempts at modeling AV impacts. He reviewed some of the assumptions made with these efforts, including increasing lane capacity, reducing the travel time variable coefficient, reducing auto operating costs, and eliminating parking constraints and costs. He suggested that these were interesting exercises to test the sensitivity of models to changes in model parameters, assumptions, and coefficients. He further suggested that enhanced model paradigms can address complex primary, secondary, and tertiary impacts. Furthermore, research is emerging that provides data on the reasonableness of different assumptions related to lane capacity of platooning vehicles and vehicle operating costs for different alternatives.

• Pendyala highlighted possible commercial vehicle applications of CV and AV technologies that could enhance the efficiency of commercial vehicle operations and reduce the need for additional infrastructure investments. He discussed some of the potential issues with mixed-vehicle operations given the uncertainty in the pace of technology availability, affordability, and adoption. He suggested that the need for mixed-vehicle operations for a considerable amount of time could emerge with a possible scenario of reduced lane capacity during this transition. In closing, Pendyala noted that in the end, the traveler still makes the choice. As a result, fundamental tenets of activity-travel demand modeling are still valid because it is the activity-travel choices of travelers that are ultimately being modeled.

PLANNING IMPLICATIONS OF VEHICLE AUTOMATION: RESULTS FROM THE PLANNING FOR VEHICLE AUTOMATION BREAKOUT SESSION AT THE 2015 AUTOMATED VEHICLES SYMPOSIUM

Jane Lappin

Jane Lappin summarized the highlights from the breakout session on planning for vehicle automation at the Automated Vehicles Symposium held in Ann Arbor, Michigan, in July 2015. She said she was speaking on behalf of Scott Smith, Volpe Center, who was one of the leads for the breakout session and the presentation. Lappin covered the following topics in her presentation:

• Discussing the motivation for the breakout session, Lappin noted the expectation that there will be increasing numbers of vehicles operating with increasing levels of automation over the next 25 years, although it is unlikely that the SAE Level 5 full automation will be realized. As a result, automation is now within the traditional long-range 25-year planning horizon, and it is beginning to receive attention in the transportation planning community.

• Lappin reviewed the breakout group agenda. The first part of the session featured speakers addressing technology, policy, and user issues. Participants discussed these issues, opportunities to reduce uncertainty, and factors to consider in the development of potential scenarios. The second part of the session focused on a scenario development process. Participants discussed some of the implications for the planning process, including activities planners can conduct over the next 5 to 10 years and what the research community can do to support these activities. Lappin noted that the 44 session participants came from universities, federal and state agencies, MPOs, consulting firms, and industries.

• Lappin reviewed the following questions raised by participants during the breakout session:

- Traditional planning uses point estimates of future demand for transportation. How does an MPO or state DOT plan for an uncertain future in today's technology, political, and legal environment?
- What changes are needed to modeling tools to better assess and address the impacts of automation?
- What will planners need to know within the next 5 years to better plan for automation?
- What questions are MPO and state DOT planners considering right now that will be affected by automation? What will transportation plans look like over the next few updates?
- What actions can be taken now to reduce future uncertainty and improve the robustness of plans?
- Going forward, what can the research community do to support planning for AVs?

• Lappin reviewed a Dutch study examining four scenarios reflecting different combinations of high versus low technology development and restrictive versus supportive AV policies. The study developed estimates for 2030 and 2050 for AV market penetration, the value of time, road capacity, and vehicle kilometers traveled. She noted that scenario planning helps identify possible boundaries for the future.

• Lappin reviewed some of the key policy and operational issues discussed in the breakout group. One topic was that planning and policy are linked. As noted in the Dutch study, policies—supportive or restrictive—do make a difference. Implications for public investment was a second topic discussed by participants. Issues discussed included the capacity of the existing infrastructure, the role of transit, and funding sources for V2I. Management and operations represented the third topic, which focused on possible changes in road performance, the impact of mixed levels of manual and automated operation, and the possibility of reduced automobile ownership.

• Lappin observed that participants in the breakout group also discussed user issues, including the willingness to use automation and the willingness to share vehicles, rides, and data. She indicated that a "user" could be a person, a household, a transit customer, or a freight provider or fleet manager. Topics discussed related to willingness to use automation included capital and per-trip costs, the willingness to cede control of driving and/or routing, and the perception of value related to safety, convenience, and the ability to multitask. Topics associated with ridesharing vehicles and data included owned versus shared vehicle costs, the convenience and perception of ridesharing, and data privacy concerns.

• According to Lappin, additional topics from the breakout group summary focused on the potential impact on demand and increases or decreases in VMT and the impact on highway capacity. Participants discussed the level of automation that should be used in the planning process. They also discussed the potential implications for infrastructure investment, including roadways, transit, and ITS, and the need to consider automation in the context of land use. Participants identified activities that could be conducted immediately to begin addressing some of these issues. Using scenario planning to explore the future was one suggestion. Possible scenario planning elements suggested by some participants included identifying key factors and driving forces that have high impacts and high uncertainty, using these factors to construct plausible future worlds, and analyzing the impacts of the issues under question on these worlds. Gaining a better understanding of AV and CV technologies and deployment activities and identifying research needs were also suggested as possible activities.

• In closing, Lappin reviewed the following possible research topics that the participants considered in their breakout groups:

- These topics included developing a robust scenario analysis, deploying and evaluating pilot projects, and assessing the attitudes of postmillennials and the possible impacts of their behavior on future travel demand.
- Other topics included assessing data from existing taxi, car, and ridesharing services; exploring interoperability across jurisdictions; and examining the capability of current travel demand models to analyze these new mobility options. More information on the breakout group is available at http://www.auvsi.org/avs2015/program/breakoutsessions/breakoutsession3.

Charles Howard, Puget Sound Regional Council, presided at this session.

PLENARY SESSION 4

Modal Applications

Steve Smith, *Robotics Institute, Carnegie Mellon University*
Christopher Poe, *Texas A&M Transportation Institute*
Stanley Young, *National Renewable Energy Laboratory*
Justin Holmes, *Zipcar*

INTEGRATING ADAPTIVE SIGNAL CONTROL WITH CONNECTED VEHICLE TECHNOLOGY

Steve Smith

Steve Smith discussed a multiyear project at Carnegie Mellon University developing and piloting an adaptive traffic signal control system for urban roads. He described the technical approach; the partners in developing and testing the system in Pittsburgh, Pennsylvania; the results to date; and future activities focusing on AVs. Smith covered the following topics in his presentation:

• Smith described a 5-year effort developing and deploying an adaptive traffic signal control system for urban road networks. He noted that the project goal is to provide real-time optimization of traffic flows for urban grid road networks. He reported that the technical approach focused on decentralized control, with coordinated action among signals. Each intersection develops its own plan for maximizing traffic flow at that intersection, with communication to downstream signals to accomplish coordination. Smith indicated that the benefits of this approach include real-time response, the ability to accommodate multiple dominant traffic flows, and scalable, incremental deployment. He reported that the system can consider other modes and provide for multimodal optimization. He reviewed the progress of the research and testing since 2010, which included development of the core approach, the East Liberty pilot deployment, and the expansion of the pilot test site. Current efforts are focusing on the integration with CV and AV technology, including DSRC.

• Smith described the basic concept of the operation plan for the scalable urban traffic control (Surtrac) system presented in Figure 3. The intersection scheduler determines the current traffic conditions, which are extracted from camera and sensor data. The system computes a phase schedule that optimizes flow at the intersection

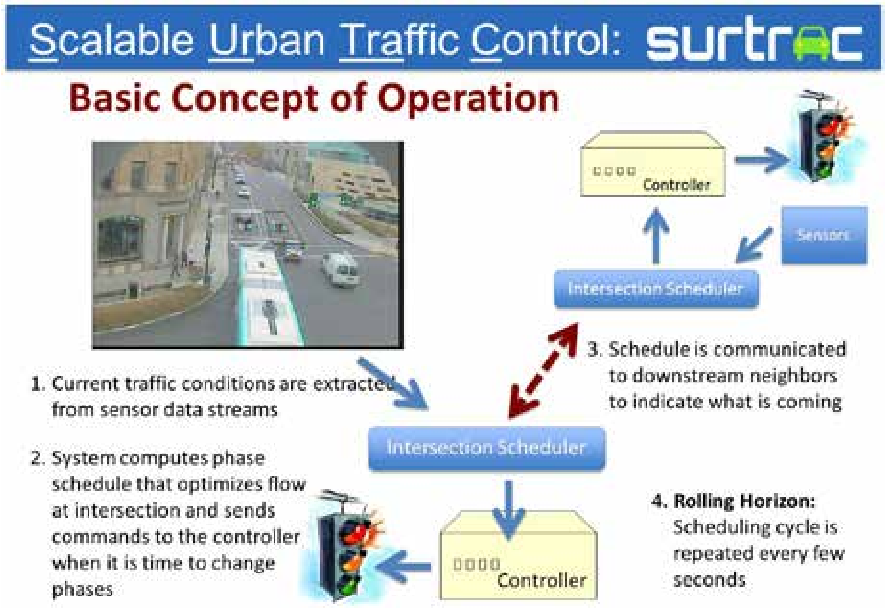

FIGURE 3 Scalable urban traffic control system concept of operation. (Source: Carnegie Mellon University.)

and sends commands to the controller when it is time to change phases. The schedule is also communicated to the downstream intersection scheduler to indicate the oncoming traffic. The downstream scheduler includes this information in developing its schedule. He noted that a rolling horizon is maintained, with the scheduling cycle repeated every few seconds. Smith described the equipment at each intersection, which includes cameras and radar, controllers, video processing boards, network connections to fiber optic cables, and Surtrac processors.

• Smith described the initial Penn Circle pilot study. He noted that the East Liberty test site was selected for a number of reasons. He reported that it was a redeveloping area of Pittsburgh with mixed commercial, retail, and residential land use. As a result, the area was experiencing changing traffic patterns and volumes. In addition, nine intersections in the area had recently been upgraded with camera detection capabilities. He noted that the partners in the pilot study included the Heinz Endowments, the City of Pittsburgh, the East Liberty Development Corporation, Traficon Traffic Video Detection, and Traffic Control Products.

• Smith discussed the performance of the Penn Circle test site, highlighting data from June 2013. He noted that travel times decreased during all times of the day, including by 30% in the morning peak period. The number of stops, wait times, and vehicle emissions also decreased during all time periods. He noted that vehicles were not necessarily traveling faster, but stopping and idling were reduced. In November 2013, the pilot was expanded to include Bakery Square. He reported that similar reductions in travel time, stops, wait times, and emissions were realized in this area.

• Smith described the expansion of the system to 49 intersections. He reported that 24 of the recently added intersections are equipped with DSRC radios and noted that these radios allow for the ongoing testing of the traffic signal system and tests involving CV and AV technologies. He described a visualization of CV activity in the corridor developed for the 2015 ITS America Annual Meeting in Pittsburgh.

• Smith discussed current V2I research focused on enhanced mobility in low–CV penetration contexts. He noted that one focus is on multimodal traffic management using integrated optimization of vehicle, pedestrian, bicycle, and transit flows. A second focus is on monitoring and shaping traffic flows through real-time route guidance and incident detection and congestion mitigation. He also observed that better sensing is an ongoing research interest.

• Smith reported there are a lot of near-side bus stops at intersections in Pittsburgh that can result in the bus blocking the traffic lane. A microscopic simulation model of Penn Circle was developed and tested to examine ways to mitigate this problem. The simulation assumed buses arriving at the Penn–Highland bus stop could be detected and that traffic would be blocked in the single eastbound lane for the entire bus dwell time. The simulation introduced a fixed delay to the start time of the platoon headed by the bus, providing more time to the cross traffic. According to Smith, the simulation results indicated that an active delay at just this intersection reduced both passenger vehicle and bus travel times through the network.

• Smith discussed a new intelligent bus prioritization project with the Port Authority of Alleghany County, the transit provider in the Pittsburgh area. The project objective focuses on active management of buses via DSRC. The project technical approach is to develop an aggregate flow model that incorporates knowledge of bus stops as DSRC information is received and to prioritize buses in an integrated way to balance overall traffic-flow efficiency. The field test will equip Port Authority buses with DSRC onboard units and measure improvements in on-time performance and other metrics. The anticipated benefits include improving bus travel times and schedule reliability while optimizing overall traffic-flow efficiency and further improving traffic flow along the Baum–Centre corridor.

• Smith noted that planned activities include the integration of real-time bus information. He noted that the DSRC onboard unit provides basic mode and location information that can be added to information from the Clever Device on-board computer. The Clever Device on-board computer has information on the bus route, whether the bus is on schedule, the number of riders on the bus, door open and close times, and bus stop requests. He commented that this information could be integrated with the traffic signal information to maximize the flow of full buses in the test corridors.

• Smith described a final future project examining real-time vehicle routing. The concept is to exploit the network-level schedule to provide real-time routing guidance. The approach would use distributed computation of the shortest path by using the most recently generated plans at each intersection. The system would fall back on historical delay information if the planning horizon is exceeded.

• In closing, Smith suggested the following three research challenges for further discussion:

- Assessing the feasibility of using occasional DSRC messages to reduce sensing uncertainty,
- Efficiently routing and rerouting vehicles with uncertain vehicle participation, and
- Determining how to ensure safety while retaining potential efficiency gains with a mix of human-operated vehicles and AVs on the roadways.

CONNECTED WORK ZONE FOR IMPROVED FREIGHT MOBILITY AND SAFETY

Christopher Poe

Chris Poe discussed some of the transportation safety and mobility challenges in Texas, the use of advanced technologies in the I-35 expansion project, and the connected work zone project. He recognized the assistance of Robert Brydia of TTI with the preparation of the PowerPoint presentation. Poe covered the following topics in his presentation:

• Poe described the transportation challenges in the Texas Triangle, which stretches from the Dallas–Fort Worth Metroplex in the north, to Houston in the southeast, and to San Antonio and Austin in the southwest. The three freeways serving the triangle are I-45 in the east, I-10 in the south, and I-35 in the west. He noted that approximately three-fourths of the state's 27 million people live within the triangle and that the Texas population is forecast to increase to approximately 45 million by 2040. He reported that 11 of the top 20 most congested roadway sections in Texas are located within the triangle, as are seven of the top 25 national freight bottlenecks. A doubling of freight tonnage in the triangle is projected from 2010 to 2040 to meet the needs of the growing population.

• Citing the TTI Urban MobilityScorecard,[1] Poe said that congestion is costing Texas approximately $9 billion per year or approximately $1,150 per commuter in the large- and medium-sized cities in the state. Further, the cost of congestion to the trucking industry was estimated at approximately $1 billion in 2014. He noted that according to data from the Texas DOT, truck crashes have been increasing, although the overall number of crashes has been declining. Approximately 15% of all crashes involve trucks, and 459 of the fatal crashes in 2014 involved trucks. Further, Texas has the most work zone fatalities in the United States, with approximately 40% of work zone fatalities occurring on Interstates and freeways. In addition, there were approximately 235 pedestrian fatalities on I-35 from 2010 through 2014.

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[1] Lomax, T., D. Schrank, and W. Eisele. *2015 Urban Mobility Scorecard*. Texas A&M Transportation Institute, College Station, Texas. August 2015.

• Poe described the approximately $2.1 billion construction project expanding 96 miles of I-35 to the north and south of Waco. The overall project includes 17 project sections with multiple contractors. He noted that approximately 55,000 to 111,000 vehicles per day travel the corridor, with trucks accounting for between 25% and 30% of the traffic. Poe reported the peak construction occurred between 2012 and 2014, with completion estimated for 2017. He noted that TTI was assisting Texas DOT in coordinating the construction process and providing information to motorists and truckers in the corridor.

• Poe summarized some of the challenges with operating work zones, including geometric constraints due to the loss of shoulders or narrow lanes and congestion resulting from lane closures. Additionally, work zones may occur at unexpected times, especially when contractors are working at night and on the weekends. Further, high volumes of trucks may be traveling through work zones, which is the case in the I-35 corridor. He noted that the rural corridor included little ITS infrastructure prior to the widening project.

• Poe described the elements implemented to assist with traffic management during construction and to provide a smart corridor after completion of the project. Examples included installing and using ITS technologies to provide travel time monitoring and displays, developing a comprehensive construction database, and estimating and posting lane closure delay projections. A good deal of effort also focused on contractor coordination and event analytics. A variety of methods, including social media, were used to disseminate information on the project and the status of traffic. Poe noted that the project team identified 30 minutes as the maximum allowable construction delay for travelers in the corridor, with contractors voluntarily coordinating phases of construction or adjusting traffic management to meet that goal.

• Poe described the ITS infrastructure installed in the corridor, which included Bluetooth, Wavetronix, and closed-circuit television. There are 43 Bluetooth sites in the corridor, which provide several thousand matches per day. The Bluetooth data are used for travel times, incident analysis, daily operation reports, and corridor delay estimates. Four years of archived Bluetooth data are available for analysis. The 19 Wavetronix sites provide bidirectional counts and classifications that are used for lane-closure impact assessments and end-of-queue analyses. There are 4 years of archived Wavetronix data. The 18 closed-circuit televisions, which provide 50 camera views, are used for traveler information, the real-time traffic map, and incident management support.

• Poe described innovative traffic management projects deployed in the Waco–Belton and Temple areas that provide comparative travel times on alternate routes. Bluetooth and closed-circuit television are used on the alternate routes, providing travelers with comparative travel times on I-35 and Loop 340 in Waco and Loop 363 in Temple. Information on traffic conditions during incidents and a real-time map are also available to travelers.

• Poe described an innovative end-of-queue warning system developed as part of the project. The project team estimates the location where the queues may form and recommends deployment of the end-of-the-queue warning system to alert drivers approaching these locations via changeable message signs. The system has been used for approximately 300 night deployments, as well as specialty deployments involving crash investigations. The system is also being installed in some semipermanent locations, including six bridges in the Waco area. He noted that Texas DOT pioneered this nightly deployment approach, which is being considered in several states.

• In describing the results from the work zone management techniques and technologies, Poe reported that less than 5% of the approximately 3,700 lane closures to date have resulted in delays of more than 30 minutes. He noted that annual surveys of travelers in the corridor indicate that approximately 87% think the information provided is nearly always accurate, and 62% reported changing travel plans based on the information. He additionally noted that TTI estimated a 20% to 40% reduction in crashes over what would have occurred if end-of-the-queue systems were not in place.

• Despite all the technologies and systems deployed in the corridor, Poe noted that crashes have still occurred. One crash involved a truck hitting a low-hanging bridge beam, even though warning signs were posted approaching the bridge. A fatality occurred when the beam fell on a vehicle traveling in the opposite direction. He suggested that providing information directly to commercial operators in their cabs may help address these issues.

• Poe described the Connected Work Zone project, which involves a U.S. DOT grant to Texas DOT to expand the Freight Advanced Traveler Information Systems Corridor Optimization for Freight project. The project partners include the U.S. DOT; Texas DOT; TTI; Productivity Apex, Inc.; and North American Strategy for Competitiveness. The project is integrating the TTI data on work zone lane closures, delays, and queues into freight logistics and trucks using CV architecture. The project will provide a demonstration of freight optimization on I-35. According to Poe, elements of the corridor optimization include providing pretrip planning for routes and loads, identifying the best windows for pickup and drop-off, and communicating real-time, dynamic updates for drivers. Approximately 150 in-vehicle devices will be used. Phase 1 focuses on using cellular communication, with DSRC communication planned for Phase 2. He noted that a U.S. DOT contractor will conduct an independent evaluation of the project.

• Poe concluded by highlighting the following potential research needs:

- One research topic was examining methods to safely deliver V2I warnings to truck drivers. He noted that some freight companies do not allow operators to access information devices in the cab while driving. Possible approaches include using aftermarket devices and integrating these devices with commercial vehicle systems.

- Other research topics he suggested were identifying communication needs, assessing potential benefits with low market penetration, and analyzing additional V2I safety and mobility applications.
- One final research topic was considering how V2I applications enhance truck platooning. He noted that TTI was working with Texas DOT on a Level 2 commercial truck platooning project. The project goal is to assess the feasibility of deploying two-vehicle truck platoons on specific corridors in Texas within the next 5 to 10 years and to create a first-of-its-kind freight Level 2 automation platooning demonstration in Texas. The project includes planning, design, system engineering, and prototype development. Project partners include Ricardo; Argonne National Laboratory; Denso; the U.S. Army Tank Automotive Research, Development and Engineering Center; Navistar; TRW; Bendix; and Lytx.

HARNESSING VEHICLE AUTOMATION FOR PUBLIC MOBILITY: AN OVERVIEW OF ONGOING EFFECTS

Stanley Young

Stanley Young discussed the potential for automated public mobility. He described the need for improved public mobility, recent urban mobility pilots in Europe, and possible future projects in the United States and England. Young covered the following topics in his presentation:

• Young compared the current situation and the space program in the 1960s, suggesting that AVs are the 21st century's race to the moon. He noted there is competition between OEMs, technology companies, countries, states, and academic institutions in developing, testing, and deploying different CV and AV applications. He also suggested that there was competition among concepts: Would AVs simply replace current personal vehicles, or would a new mobility system evolve? He noted that the term public mobility was used deliberately in the title to his presentation, as public transit, which has a negative connotation for many people, is typically associated with publicly owned and operated bus, light rail, and commuter systems. He described public mobility as moving people more efficiently, apart from owning and operating a personal vehicle. Public mobility encompasses traditional public transit, but, more importantly, it also encompasses new methods to provide mass mobility through vehicle automation, communications, and shared vehicle fleets (whether publicly or privately owned).

• Young noted that public mobility will become increasingly important with global urbanization. Currently, over 50% of the global population lives in cities, and this figure is projected to increase to 66% by 2050. Further, he noted that approximately 70% of greenhouse gases are emitted in cities. Rather than continue along the path of escalating traffic congestion, Young suggested that a purpose-built, fully automated mobility system is possible that reduces or eliminates congestion and could capture the energy efficiency of an electrified, centrally managed fleet.

• Young described five of the urban mobility pilots in the European Commission–sponsored CityMobil2 program. He noted that municipalities participating in the pilots had to approve legislation allowing autonomous vehicles to operate on public streets. Legal precedent for such systems is one of the major objectives of the CityMobil2 program.

• The pilot program in the city center of La Rochelle, France, was in operation from December 2014 to April 2015. The objectives of the pilot included gauging public reaction and social response to the use of robotic vehicles providing public transport in addition to technology and safety objectives. Approximately 15,000 passengers used the Robosoft vehicles in 4 months of operation, with 70 people riding on a regular basis.

• The pilot in Lausanne, Switzerland, focused on a college campus. It was in operation for 5 months in early 2015 and included a smartphone app for summoning a ride. The pilot linked public transport services on the southern and northern edges of the campus. Four shuttles served six stops on a 1.5-km itinerary, with service provided weekdays from 7:45 a.m. to 10:00 p.m. The pilot recorded approximately 7,000 passenger boardings over 5 months.

• Two smaller-scale demonstrations took place in Italy and Finland. The pilot in Oristano, Sardinia, included two vehicles operating for 1.3 km, with seven stops on the Sea Front Promenade. The promenade includes intense pedestrian traffic and crossing traffic consisting primarily of service vehicles. The pilot operated for 6 weeks during the summer of 2014. The pilot in Vantaa, Finland, connected a train station and a housing development approximately 1 mile away. The system operated on weekends during the housing fair in the summer of 2015. The pilot used four EZ-10 vehicles that accommodated 10 passengers (six seated and four standing). Approximately 1,100 people used the system on the weekends, and the system accumulated over 19,000 riders during the 1-month pilot.

• The pilot in Trikala, Greece, is being operated from September 2015 through February 2016. Six vehicles operate on a dedicated asphalt lane for approximately 2.5 km. Young noted that a national law for automated transport was passed in Greece, whereas the other demonstrations were enabled by city or regional legislation. The national law is an indication of the anticipation of mobility services based on fully automated vehicles.

• Young discussed the significance of the CityMobil2 pilots. Obtaining the legal framework was a prerequisite for hosting a pilot demonstration. The pilots illustrated that there is social acceptance of robotic shuttles intermixing with pedestrians and vehicles. It was noted that the applications were purpose-driven, application-oriented demonstrations. The applications included a city center circulator, a last-mile solution for regional transit, extending transit ridership, a university campus circulator, and a recreational area circulator. Although the technology was adequate for the demonstration, areas for improvement were identified.

• In October 2015 GoMentum Station, the Contra Costa Transportation Authority–Concord, California, testing ground for autonomous vehicles, announced a planned demonstration partnership with EasyMile, one of the technology providers for CityMobil2. The target is to operate two EasyMile vehicles at Bishop Ranch, a 585-acre office park north of Oakland, California, in 2016.

• Young described the Milton Keynes pilot in England, which is also in the planning stage. The pilot will deploy a 40-car fleet consisting of Electric Lutz Pathfinder vehicles, which hold two people each and can travel up to 15 mph. The vehicles will operate in separate lanes to avoid pedestrians. The pilot is part of a 5-year, £120 million project targeted to be operational by mid-2017.

• Young noted other planned demonstration projects and activities recently featured in the news including testing driverless robot taxis in Japan; the world's first driverless bus in Yutong, China; and the Honda Wander Stand introduced at the 2015 Tokyo Motor Show.

• Young suggested that fully automated mobility systems are not completely new, as there are several examples of purpose-built automated people-mover systems in operation in constrained environments. Examples include the personal rapid transit system at the University of West Virginia campus in Morgantown, opened in 1975; the personal rapid transit system implemented in the late 1990s in the Business Park Rivium, Capelle aan den Ijssel, Netherlands; and the Heathrow Airport Terminal 5 personal rapid transit system, which opened in 2011. Automated systems with larger vehicle sizes are also common in many airports.

• In closing, Young noted the potential of fully automated systems in urban areas to alter the access dynamics of the community. He suggested the concept of automated shuttles or pods forming the basis of an automated mobility district in congested areas. This approach could increase the effectiveness of transit access, increase carsharing and vehicle-sharing opportunities, minimize vehicle access to the city, and ease parking. He further suggested that autonomous shuttles could enable car-free zones, with numerous benefits realized from more robust trip-making options, delivering benefits similar to transit-oriented development, but doing so using automated systems on public roadways.

ZIPCAR: AUTOMATED VEHICLES AND THE FUTURE OF URBAN MOBILITY

Justin Holmes

Justin Holmes provided an introduction to Zipcar and discussed its role in the future of urban mobility. He highlighted the development, growth, and current status of Zipcar and discussed opportunities for integrating carsharing services and autonomous transportation systems. Holmes covered the following topics:

• Holmes noted that Zipcar, as a private company, is very purpose oriented. Zipcar provides members with an alternative to owning a private vehicle and enables them to live a car-free lifestyle. He noted that the Zipcar mission is to enable simple and responsible urban living. This social mission was a key element when the company was founded 15 years ago in Cambridge, Massachusetts, by two female entrepreneurs who had the vision that carsharing may one day surpass car ownership. The company began with one VW Bug in Central Square in Cambridge. He noted that at the time many people thought the idea was crazy, that Americans would never give up owning a car to share a car with others. Holmes reported that today, Zipcar has nearly 1 million members worldwide sharing over 10,000 vehicles in seven countries. Zipcar is located in more than 500 cities and towns and some 500 university campuses.

• Holmes discussed the Zipcar business model, which provides a viable alternative to automobile ownership for individuals and businesses. Zipcar members have access to vehicles for planned and spontaneous trips by the hour or by the day, 24 hours a day, 7 days a week, at locations throughout a city. Gasoline and insurance are included. The intent is to provide a simple alternative to owning a vehicle, with the same sense of freedom associated with automobile ownership.

• Holmes suggested there were three major factors supporting the development of Zipcar and carsharing as a viable option in dense urban environments. The first was the simple but elegant design of the system and the continued evolution of supporting technology. The second factor was changing attitudes toward automobile ownership among the millennium generation and other groups. The third factor was the economy. With transportation being the number two cost after housing for most individuals, carsharing provides a rational, cost-effective option for many city residents. He cited parents bringing their new babies home from the hospital in New York City as an example of the viability, customer orientation, and reliability of carsharing services. He also noted it was an example of the trust and confidence Zipcar members have in the service.

• Holmes described the diverse Zipcar fleet, which includes over 50 makes and models. He noted that diversity was important to meet the different trip needs of members. He also noted that Ford and Honda are strategic partners. The technology Zipcar uses is compatible across many vehicle makes and models.

• Holmes reported that Zipcar refers to members as “Zipsters.” He noted there is a misperception that only millennials use carsharing services, when in fact Zipsters range in age from 18 to 92. He discussed the recent strategic agreement between Zipcar and AARP to meet the needs of people retiring in place, as well as those retiring with homes in two states. He also noted that Zipcar provides an option for individuals not able to afford a personal vehicle.

• Holmes summarized recent research conducted by Susan Shaheen at the University of California, Berkeley, which indicates that each Zipcar eliminates approximately 13 personally owned vehicles. Further, after eliminating their personal vehicle, Zipcar members reported a 13% increase in bicycling trips and a 19% increase in walking trips. Further, Zipcar members spend less of their income on transportation compared to automobile owners, with an average savings of $600 a month. As a result, he suggested that Zipcar and other carsharing services help reduce VMT and traffic congestion and enhance environmental sustainability.

• Holmes described the important relationship between carsharing and public transportation. He noted that three growth enablers for Zipcar were density, access to public transportation as the backbone service, and public policy. He illustrated the Zipcar locations at stations along the Massachusetts Bay Transportation Authority rail system in Boston. He suggested that integrating carsharing services into future transit and transportation projects would enhance mobility and reduce costs for individuals.

• Holmes described the importance of continuous innovation at Zipcar. He noted that Zipcar's original model was round-trip carsharing. Realizing individuals have other travel needs, Zipcar launched a pilot in Boston in 2014 with one-way, point-to-point service coupled with the ability to reserve an on- or off-street parking space. He noted that this service has been very well received by Zipcar members and has helped reduce congestion caused by motorists searching for open parking spaces.

• Holmes discussed possible approaches for integrating carsharing with autonomous transportation systems. He suggested that Zipcar and other carsharing services have demonstrated the benefits and user acceptance of access to a vehicle over ownership of a vehicle. He noted that Zipcar brings experience and expertise in fleet operations and maintenance, including keeping 10,000 vehicles clean and filled with gasoline. He also noted Zipcar's experience with using a distributed parking footprint, the strategic partnerships with OEMs, the use of in-vehicle technology and innovation, the link to transit ecosystem partners, and the relationships with cities as key elements supporting a successful autonomous transportation deployment. He further suggested that Zipcar's loyal and trusted membership provides a base for autonomous transportation users. He commented that although Zipcar, operating as a private company, has a profit motive, it also has a social mission. He suggested that a Zipcar enabled by autonomous vehicle technology would be a very powerful combination.

• In closing, Holmes noted that more people will be living in cities in the future. These cities are not able to handle more single-occupant vehicles. He noted that carsharing can help address a concern that autonomous vehicles could result in more zero-occupant vehicles. He suggested that future collaboration among autonomous transportation, carsharing, and transit would be a powerful combination for smarter communities. Based on the Zipcar experience, he indicated that carsharing is a viable and proven economic model.

Robert Bertini, California Polytechnic State University, San Luis Obispo, presided

Reports from the Breakout Discussion Groups

Steven Shladover, *California Partners for Advanced Transportation Technology*
Patrick Szary, *Rutgers University*
Charles Howard, *Puget Sound Regional Council*
Robert Bertini, *California Polytechnic State University, San Luis Obispo*
Melissa Tooley, *Texas A&M Transportation Institute*

BREAKOUT GROUP 1: INSTITUTIONAL AND POLICY

Steven Shladover

Steven Shladover summarized the following six topic areas discussed by participants in the institutional and policy breakout session:

• A first general topic area focused on AV technology and ensuring that AVs operate safely in all types of environments. A number of participants considered the AV certification procedure, which could be harmonized across all states and with other countries. In addition, they considered testing processes and testing protocols that account for the great diversity of AV system requirements, operational design domains, and levels of automation, all of which can ensure safe operations. Approaches to maximize cyber security were explored by breakout participants. Considering a proactive European-style regulatory regime rather than the current reactive FMVSS regime was suggested by some breakout participants. The relative federal and state roles for encouraging or informing the safety of deployed vehicle systems were discussed by other participants.

• A second general topic area addressed in the breakout groups focused on regulating drivers and users of AVs and CVs. One issue discussed was developing procedures to qualify people to use AVs, including those who are not currently licensed drivers because of age, disease, or other disabilities. Participants explored the possible roles and responsibilities of the agency certifying that a driver is qualified to operate a specific AV and possible factors that could be used to rate drivers for licensing. Training and education on the capabilities and limitations of AVs and the relative roles and responsibilities of the manufacturer, dealer, and public regulators, such as DMVs, were also discussed. Possible research topics suggested by different participants included examining the experience with graduated driver licenses, consumer market acceptance levels among different driver age groups, and the need for driver testing or monitoring at lower levels of automation. Participants also discussed how tickets would be assessed if an AV violates a traffic law.

• The third general topic area focused on the interaction of AVs with other road users. Participants discussed whether AVs should be required to have external markings or some indication when automated operation is in use. Issues relating to standardizing these external markings were discussed by participants, as was ensuring the safety of small AVs that are intended to operate at low speeds in pedestrian and bicycle paths or lanes.

• The fourth general topic area focused on public agency roles and responsibilities with AV deployment. Participants discussed roles related to regulations, infrastructure, vehicle and driver licensing, and law enforcement. The potential to modify infrastructure to accommodate AVs and CVs was also considered, along with possible costs and funding sources, and issues related to harmonizing regulations across local areas, states, and countries. Participants discussed possible conflicts between AVs, CVs, and existing vehicles. Some participants questioned if public agencies are agile enough to respond to AV deployment needs and discussed possible approaches for public agencies given the uncertainty about AV performance, functionality, and market growth.

• The fifth general area addressed the transportation system and societal impacts of AVs and CVs. Participants debated the possible net impact on traffic congestion, accounting for the divergent effects of close vehicle spacing, smoother traffic flow, latent demand from accomplishing other tasks when individuals are not “driving,” and empty backhauls associated with repositioning AVs. The possible impacts—both positive and negative—on public transportation, including paratransit and social service transportation for individuals unable to drive, were discussed. Some participants suggested that additional research on these topics would be beneficial.

• The sixth topic area explored in the breakout group focused on the research process. Participants questioned whether the existing research process was agile enough to produce timely results in a rapidly changing environment, and they subsequently discussed approaches to accelerate the research process. Some participants also questioned if adequate resources would be available for needed research given the budget limitations being faced by many public agencies. Maintaining support for research and identifying and promoting critical research areas were also discussed by participants.

BREAKOUT GROUP 2: INFRASTRUCTURE DESIGN AND OPERATIONS

Patrick Szary

Patrick Szary summarized the following topics discussed in the infrastructure design and operations breakout group:

• Participants in the breakout group discussed a wide range of topics associated with security, including cyber security, physical security, infrastructure security, spectrum security, and individual security. The potential use of AVs as a weapon of mass destruction was considered by participants, as were ways that people could try to break into the different systems and technologies. Participants noted that many of the security issues were not unique to AVs and CVs, but they suggested extra caution was needed given the high visibility and interest in AVs, CVs, and shared mobility services. Concerns related to the available spectrum, competing users, security, international interference, and costs were also discussed, as were potential impacts of AVs and CVs on the electrical power grid.

• Improvements and changes to the transportation infrastructure to accommodate AV and CV deployment represented a second topic discussed by breakout group participants. The roles and responsibilities of public agencies in making needed improvements and in ongoing operations and maintenance were also considered. Addressing these needs with limited funding was noted as a possible challenge for transportation agencies. Breakout group participants discussed the potential need to repurpose existing infrastructure, such as dedicating existing travel lanes as truck-only lanes, narrowing lanes, and removing on-street parking. Participants suggested the need to consider possible design and operational issues with these changes and noted that research on these topics would be beneficial. They then considered the capabilities of computer vision systems in cold weather, and the potential for snow, ice, and deicing chemicals to obscure lane markings and other boundaries. The technologies being incorporated into windshields were discussed, with options suggested for addressing possible vision and sensing concerns. Participants also discussed possible infrastructure standards for AVs and CVs.

• Breakout group participants discussed the differences in opinion on the time period and the path for AV and CV deployment and the impacts of these different scenarios on infrastructure, operations, and maintenance. The transition period with all types of vehicles operating on the roadway system was also discussed. It was also noted that the various sensor, camera, and other technologies would continue to evolve rapidly with ongoing impacts on operations and maintenance.

• One suggestion discussed by breakout group participants was the application of AV and CV technologies for dynamic work zones. One concept focused on incorporating changes in work zone lane markings into heads-up displays controlled through software. It was suggested that this approach would address concerns with overlapping old and new lane markings, which can confuse drivers. It was further noted by some participants that other technologies could be applied to enhance work zone operations to improve the safety of drivers and workers.

• Breakout group participants discussed funding issues associated with the various infrastructure, operations, and maintenance activities. The potential for public–private partnerships to provide funding was discussed by participants. It was also suggested there may be misperceptions on the part of policy makers and the public on the timeliness and availability of AVs and CVs. Providing information on realistic expectations was noted as one possible role for transportation agencies. Participants also discussed issues related to compatibility among different technologies and approaches. Although standards may be needed, some participants suggested it may be too early to adopt specific standards as doing so may inhibit innovation. Participants noted that with the apparent movement toward a sharing economy, individual vehicle ownership may someday be a thing of the past. Some participants thought the future may focus more on dynamic transit systems, shared vehicle ownership, and new mobility services.

BREAKOUT GROUP 3: PLANNING

Charles Howard

Charles Howard summarized the following topics discussed in the planning breakout group:

- Breakout group participants noted that long-range transportation planning is difficult with all the uncertainties surrounding the possible timelines and scenarios for AV and CV deployment. Participants observed that long-range planning always deals with uncertainty, however, and that although the issues today are more challenging, they can be addressed in a logical manner with the realization that AVs and CVs may be a major game-changer.
- Participants suggested that a key role for planners in the short term may be to help provide accurate information to policy makers and the public to counteract some of the hype and misperceptions that exist related to AVs and CVs. Breakout group participants cited the ongoing transportation planning process as a good mechanism to monitor developments in AVs and CVs and to provide consistent information to decision makers and the public.
- Howard suggested that planners may benefit from thinking differently about planning by focusing on the "year of decision" concept. He noted that this concept recognizes that some projects or improvements have earlier decision dates and others have later decision dates. It focuses the planning process on the target decision dates, with an understanding that the projects with decision dates further into the future may be less certain and less well defined. He suggested that although long-range plans have always been less specific in later years, the year of decision method more openly acknowledges uncertainty and better links project decisions to key points in time. He noted that planners can monitor AV and CV deployments and incorporate evolving technology into the planning process, making adjustments as project decision years approach.

• Breakout group participants discussed the differences between AVs and CVs and the impacts these differences have on the transportation planning process. It was noted that the time frame for CVs may be earlier and that the planning process may need to address V2I issues in the near term. Participants also discussed different deployment scenarios. It was suggested that although broadband scenarios were useful for long-range planning, more detailed scenarios are needed to better understand travel behavior, consumer adoption, and market acceptance. Breakout group participants also noted that many other factors should be considered, including job and housing locations, land use policies, and energy costs. Participants suggested that private-sector groups are conducting numerous market research efforts related to AVs and CVs and that the planning process would benefit from access to the results of these activities.

• Breakout group participants also discussed the impacts of AVs and CVs on freight and goods movement. It was suggested that logistic companies may be some of the early adopters of AV and CV technologies because they own vehicle fleets. Participants noted that including the potential impacts on freight transportation in the long-range planning process was important, including the use of drones for first- and last-mile pickup and delivery services.

BREAKOUT GROUP 4: MODAL APPLICATIONS

Robert Bertini

Robert Bertini summarized the following seven general topic areas discussed by participants in the modal applications breakout session:

• A first general topic discussed by participants in the breakout group was the expanded array of individual and shared mobility solutions that will be available in the future. It was suggested by some participants that these services will better match capacity and service characteristics to the demand and needs of travelers and shippers. Participants further suggested that solutions in the future could be tailored to specific problems, with less wasted capacity and vehicle movement, which would result in energy, emissions, and fuel savings. The potential for greater public–private cooperation in the future was noted by some, as was the possibility to enhance paratransit and other social service systems. Other participants suggested that research to better understand the impact of shared mobility services on transit would be beneficial. It was noted that this topic is being considered in the current Transit Cooperative Research Program Project H-51, Understanding Changes in Demographics, Preferences, and Markets for Public Transportation. Outreach to the transit community on the current National Cooperative Highway Research Program Project 20-24(98)B project, Connected/Automated Vehicle Research Roadmap for AASHTO, was also suggested. Further, participants commented that there are available technologies that could be added now to transit vehicle procurement specifications, such as DSRC and driver assistance systems, to improve transit operations.

• Bertini noted that equity considerations represented a second general topic discussed by breakout group participants. Possible considerations associated with the Americans with Disabilities Act were considered, as were the benefits that AVs and CVs could provide to individuals who are not able to drive for various reasons. Ensuring that modal applications enabled by AVs and CVs do not discriminate against individuals and different user groups was noted as important by participants, and others suggested that transit operators may need to play different roles in the future as shared AV-CV mobility services become more widespread.

• A third general topic area discussed by breakout group participants was the use of shared AV and CV services for the first- and last-mile connection to existing transit and transportation systems for the movement of people and goods. Participants suggested that shared AV and CV services provided opportunities to enhance first- and last-mile freight and passenger travel and further suggested that research to better understand traveler behavior with shared mobility would be beneficial. Some breakout group participants also observed that opportunities exist for the automation of paratransit services, which is being demonstrated in various cities in Europe.

• The need for new business models represented a fourth general topic area examined in the modal applications breakout session. The concept of a “trusted broker” for receiving and managing data for truck platooning, paratransit services, and other applications was suggested by some participants. This approach could ensure that data are available to all participants, while overcoming privacy and competitiveness issues. Participants also suggested that it would promote public–private partnerships and cooperation toward shared societal goals.

• A fifth general topic explored in the breakout group was institutional barriers to the testing and deployment of AVs, CVs, and shared mobility services. Addressing possible legislative and labor issues was discussed as a transition toward automation occurs. Participants also considered the environment for early adoption of full automation and possible incentives for users.

• Decision-making tools represented the sixth general topic discussed by breakout group participants. It was suggested that a broad effort aimed at identifying the benefits and costs of increasing levels of connectivity and automation would be beneficial for modal applications, particularly transit, to gain support from policy makers. Participants also noted that specific tools were needed to help quantify benefits from different levels of automation.

• Education and workforce development was the final general topic examined in the breakout group. Participants expressed interest in developing a research “one stop shop” containing results and syntheses of ongoing and previous research. Participants suggested that a capacity-building program focused on education, training, and workforce development initiatives would be beneficial. It was noted that public agencies often have a difficult time managing, developing, specifying, and acquiring technology today and that these needs will be heightened in the future as agencies need to quickly acquire knowledge and technical capabilities related to V2I, V2V, and shared mobility applications. Participants discussed many of the misperceptions circulating about AVs and CVs and when transitions will occur. One idea explored by participants was developing a plan for a set of "transit building blocks toward automation," beginning with existing advanced technologies (e.g., automatic vehicle location, automatic passenger counters, and precision docking) and moving toward AV and CV technologies. Workforce development and training for the next generation of bus, transit, and vehicle drivers and operators if their "driving" skills are not needed was also suggested by participants.

CLOSING COMMENTS

Melissa Tooley

Melissa Tooley added a few comments from the presentations in the opening session. She noted that a variety of data issues were discussed by speakers including data quality, data security, data calibration, data privacy, and access to big data. Other comments focused on education and workforce development for the skill sets needed for deploying and operating AV and CV systems. Additional topics included cyber security, public education and outreach, performance measurement, and quantifying the benefits from AVs and CVs. She suggested that all of these topics would benefit from additional research.

In closing, Tooley thanked all the attendees for their active participation in the conference. She also recognized and thanked the conference planning committee and TRB staff for their hard work in organizing the conference and OST-R for their support of the conference.

APPENDIX A

Posters

INSTITUTIONAL AND POLICY

Opportunities for Automated and Connected Vehicles to Improve Mobility and Access for People Unable to Drive

Frank Douma, Adeel Lari, and Leili Fatehi, University of Minnesota

User Adoption for Connected and Automated Vehicles: What Can We Learn from Previous Experiences?

Mohammad Lavasani and Xia Jin, Florida International University

INFRASTRUCTURE DESIGN AND OPERATIONS

Vehicular Ad Hoc Network (VANET) Simulations of Passing Maneuvers on Two-Lane Rural Highways

Michael Motro, Alice Chu, Rahi Kalantari, Junil Choi, Jie Xu, Joydeep Ghosh, Robert Heath, and Chandra Bhat, University of Texas at Austin; and Abdul Pinjari, University of South Florida

Monitoring Pavement Conditions Using a Connected Vehicle–Enabled Application

Huanghui Zeng, Battelle Memorial Institute; and Brian Smith and Hyungjun Park, University of Virginia

Signal Control Optimization and Simulation for Automated Vehicles at Isolated Intersections

Zhuofei Li and Lily Elefteriadou, University of Florida

Quantifying the Benefits and Costs of Virtual Dynamic Message Signs Relative to Traditional Dynamic Message Signs Using a Case Study of the I-66 Connected Vehicle Testbed

David Recht, Hyungjun Park, and Brian Smith, University of Virginia; and Alona Green, Morgan State University

PLANNING

The Impact of Activities While Traveling on Commute Mode Choice in an Autonomous Vehicle Future: Simulations Based on a Revealed-Preference Model

Aliaksandr Malokin, Patricia Mokhtarian, and Giovanni Circella, Georgia Institute of Technology

The Implications of Automated and Connected Vehicle Technologies on Travel Behavior and Modeling

Mohammad Lavasani and Xia Jin, Florida International University

Consumers' Perception, Intended Adoption, and Travel Behavior Impacts of Automated Vehicle Technology: Findings from a Multi-University Population Survey in Florida

Nikhil Menon, Abdul Pinjari, and Yu Zhang, University of South Florida; Siva Srinivasan, University of Florida; Xia Jin, Florida International University; and Naveen Eluru, University of Central Florida

Creating Livable Communities Through Connecting Vehicles to Pedestrians and Cyclists

John MacArthur, Portland State University

MODAL APPLICATIONS

Bicyclists and Connected and Autonomous Vehicles

Ken McLeod, League of American Bicyclists

Human Factors Evaluation of an In-Vehicle Active Traffic and Demand Management (ATDM) System

Kayla Sykes, Alexandria Noble, Zachary Doerzaph, Thomas Dingus, Pamela Murray-Tuite, and Luke Neurauter, Virginia Polytechnic Institute and State University

Dynamic and Real-Time Traffic Signal Coordination Tuning Model for Signalized Arterials Within Connected Vehicle Environment

Zhitong Huang, Turner–Fairbank Highway Research Center and Mississippi State University; Li Zhang, Mississippi State University; Deborah Curtis and Govindarajan Vadakpat, Federal Highway Administration; and David Hale, Leidos Inc.

Congestion Shockwave Damping Through Cooperative Adaptive Cruise Control (CACC) with Variable System Response Time

Yizhou Wang and Peter J. Jin, Rutgers University; and Haiyan Gu, University of Southeast, China

Dynamic Merge Assistance Based on V2I (Vehicle-to-Infrastructure) Communication in Connected Vehicle Environment

Yizhou Wang, Xiaowen Jiang, and Peter J. Jin, Rutgers University; and Xia Wan, University of Wisconsin–Madison

Pilot Study: Effects of the Incorporation of Wireless Communication–Enabled and Autonomous Vehicles on Traffic Congestion and Safety

Claire Silverstein and Samer Hamdar, George Washington University

Predictive Control of a Vehicle Convoy Considering Lane Change Behavior of the Preceding Vehicle

Peng Liu, Arda Kurt, Keith Redmill, and Umit Ozguner, Ohio State University

OTHER TOPICS RELATED TO AUTOMATED VEHICLES AND CONNECTED VEHICLES

Improved Warning and Control Assistance Information Embedded in Basic Safety Messages Transmitted Between Connected Vehicles

Asad Khattak, University of Tennessee

Identifying Safety-Critical Events Using the Basic Safety Message

Robert Kluger and Brian Smith, University of Virginia

Developing a Spatial–Temporal Dimension Extension-Based Autonomous Intersection Control Strategy for Connected Autonomous Vehicles

Qiong Wu, Cheng Wang, Cong Chen, Guohui Zhang, and Rafiqul Tarefder, University of New Mexico; and Zong Tian, University of Nevada

Optimal Intersection Control of Automated and Cooperative Vehicles

Youssef Bichiou, Hesham Rakha, Mohammed Almannaa, and Ahmed Roman, Virginia Tech Transportation Institute

U.S. DOT FHWA Intelligent Transportation Systems (ITS) Professional Capacity Building (PCB) Program: An Overview of ITS PCB Program Resources and Academic Links

Judy Yahoodik, Volpe Center, U.S. Department of Transportation

A Scalable Force Terrain Model for Microscopic Simulation of Connected and Autonomous Transport

Bumjoon Bae, Hyeonsup Lim, Yang Zhang, and Lee Han, University of Tennessee

Energy and Greenhouse Gas Emissions Impacts of Autonomous Vehicles

Regina Clewlow, Stanford University

Minimum Time to Situation Awareness During Transfer of Control in Autonomous Driving

Siby Samuel and Donald Fisher, University of Massachusetts, Amherst

Personal Intersection Speed Advisory System

Slobodan Gutesa, Joyoung Lee, Dejan Besenski, and Branislav Dimitrijevic, New Jersey Institute of Technology

Texas Technology Task Force: A Platform for Identifying, Evaluating, and Leveraging Emerging Technologies

Andrea Gold, Kristie Chin, and C. Michael Walton, Center for Transportation Research, University of Texas at Austin

APPENDIX B
Conference Participants

Osman Altan, Federal Highway Administration
Bumjoon Bae, University of Tennessee, Knoxville
Carla Bailo, Ohio State University
Michael Baldwin, U.S. Department of Transportation
Jim Barbaresso, HNTB Corporation
Andy Berthaume, U.S. Department of Transportation
Robert Bertini, California Polytechnic State University
Nahom Beyene, RAND Corporation
Chandra Bhat, University of Texas at Austin
Youssef Bichiou, Virginia Tech Transportation Institute
Nicholas Bleich, U.S. Department of Transportation
Thomas Bolle, U.S. Department of Transportation
Ed Bradley, Toyota
Raj Bridgelall, Upper Great Plains Transportation Institute
Alasdair Cain, U.S. Department of Transportation
Stan Caldwell, Carnegie Mellon University
Jennifer Carter, ITS America
Mecit Cetin, Old Dominion University
Cong Chen, University of New Mexico
Mei Chen, University of Kentucky
Shyuan-Ren Chen, Federal Highway Administration
Ashwini Chhabra, Uber Technologies, Inc.
Kristie Chin, University of Texas at Austin
Madhav Chitturi, University of Wisconsin–Madison
Alice Chu, University of Texas at Austin
Regina Clewlow, Stanford University
Edward Collins, Allstate Insurance
Seyedehsan Dadvar, Morgan State University
Jennifer Dill, Portland State University
Max Donath, University of Minnesota
Kevin Dopart, ITS Joint Program Office, U.S. Department of Transportation
Frank Douma, University of Minnesota
Lili Du, Illinois Institute of Technology
Denise Dunn, U.S. Department of Transportation
David Eby, University of Michigan Urban Transportation Research Institute
Lily Elefteriadou, University of Florida
Andrew Farkas, Morgan State University Transportation Center
Volker Fessmann, Federal Highway Administration
David Fitzpatrick, Booz Allen Hamilton
Ross Froat, American Trucking Associations

Chris Gerdes, Stanford University
Jeff Gerlach, Securing America's Future Energy
Stephen Glascock, Louisiana Department of Transportation and Development
Andrea Gold, University of Texas at Austin
Jeff Gonder, National Renewable Energy Laboratory
Slobodan Gutesa, New Jersey Institute of Technology
Samer Hamdar, George Washington University
Takeshi Hasegawa, Louis Berger
Imran Hayee, University of Minnesota, Duluth
Dennis Hinebaugh, University of South Florida
Justin Holmes, Zipcar
Jill Hough, Upper Great Plains Transportation Institute
John Hourdos, University of Minnesota
Charlie Howard, Puget Sound Regional Council
Jude Hurin, Nevada Department of Motor Vehicles
Ijeong Im, Hongik University
David Jackson, U.S. Department of Transportation
Shawn Johnson, U.S. Department of Transportation
Reuben Juster, University of Maryland
Camille Kamga, University Transportation Research Center, City College of New York
Asad Khattak, University of Tennessee
Robin Kline, U.S. Department of Transportation
Robert Kluger, University of Virginia
James Kuehn, Independent Consultant
Jane Lappin, U.S. Department of Transportation
Mohammad Lavasani, Florida International University
Joyoung Lee, New Jersey Institute of Technology
Kenneth Leonard, U.S. Department of Transportation
Xiaopeng Li, University of South Florida
Peng Liu, Ohio State University
Stephen Lockwood, Steve Lockwood, LLC
John MacArthur, Transportation Research and Education Center
Jane Macfarlane, HERE–Nokia
John Maddox, Mobility Transformation Center, University of Michigan
Aliaksandr Malokin, Georgia Institute of Technology
Russ Martin, American Automobile Association
Tanner Martin, Florida Department of Transportation
Keith Marzullo, Federal Networking and Information Technology Research and Development Program, National Coordination Office
John Mason, Auburn University
Laurie McGinnis, Center for Transportation Studies, University of Minnesota
Ken McLeod, League of American Bicyclists
Ronald Medford, Google, Inc.
Nikhil Menon, University of South Florida

Lydia Mercado, U.S. Department of Transportation
David Metcalf, ATCS, P.L.C.
Sheryl Miller, Toxcel
Lisa Molnar, Transportation Research Institute, University of Michigan
Carlos Monje, Jr., U.S. Department of Transportation
Newton Montano, Trams International
Dick Mudge, Compass Transportation and Technology
Kevin Mundt, Fiat Chrysler Automobiles, US LLC
Mark Muriello, Port Authority of New York and New Jersey
Santiago Navarro, U.S. Department of Transportation
Mark Norman, Transportation Research Board
Thomas O'Brien, California State University, Long Beach
Hyungjun Park, University of Virginia
Ellen Partridge, U.S. Department of Transportation
Ram Pendyala, Georgia Institute of Technology
Karen Philbrick, Mineta Transportation Institute
Christopher Poe, Texas A&M Transportation Institute
Zhen Qian, Carnegie Mellon University
Fengxiang Qiao, Texas Southern University
Hesham Rakha, Virginia Tech Transportation Institute
Jeffrey Randall, Jacobs Engineering Group
Jeremy Raw, Federal Highway Administration
Mark Reichert, Florida Transportation Commission
Raymond Resendes, Virginia Tech Transportation Institute
Jonathan Riehl, Traffic Operations and Safety Laboratory, University of Wisconsin
Zachary Rubinstein, Carnegie Mellon University
Siby Samuel, University of Massachusetts, Amherst
Reuben Sarkar, U.S. Department of Energy
Ted Scott, American Trucking Associations
Helen Serassio, U.S. Department of Transportation
David Sherman, HNTB Corporation
Hyeon-Shic Shin, Morgan State University
Steven Shladover, California Partners for Advanced Transportation Technology
Sophie Shulman, U.S. Department of Transportation
Claire Silverstein, George Washington University
Burney Simpson, Driverless Transportation
Caesar Singh, U.S. Department of Transportation
Brian Smith, University of Virginia
Matthew Smith, Michigan Department of Transportation
Stephen Smith, Carnegie Mellon University
Nazy Sobhi, U.S. Department of Transportation
Dustin Souders, Florida State University and Turner–Fairbanks Highway Research Center
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