Towards Road Transport Automation: Opportunities in Public-Private Collaboration

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Towards Road Transport Automation

Opportunities in Public–Private Collaboration

Summary of the Third EU-U.S. Transportation Research Symposium

Katherine F. Turnbull
Rapporteur

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Organized by the
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European Commission
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This report has been reviewed by a group other than the authors according to the procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the National Academy of Medicine.

This project was organized by the U.S. Department of Transportation, the European Commission, and the Transportation Research Board.

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Preface

This document summarizes the symposium *Towards Road Transport Automation: Opportunities in Public–Private Collaboration*, which was held April 14 and 15, 2015, at the National Academy of Sciences Building in Washington, D.C. This symposium was the third in a series of four annual symposia sponsored by the European Commission and the U.S. Department of Transportation and organized by the Transportation Research Board (TRB) of the National Academies of Sciences, Engineering, and Medicine. The goals of the symposia are to promote common understanding, efficiencies, and transatlantic cooperation within the international transportation research community while accelerating transport-sector innovation in the European Union and the United States.

The 2-day, invitation-only symposium brought together high-level experts to share their views on the future of surface transport automation from the technological and socioeconomic perspectives. Recognizing the importance of the emerging transport automation ecosystem, participants came from public agencies, the automotive and technology industries, academia, consulting firms, and other groups key to implementation of road transport automation.

A bilateral planning committee was assembled by TRB and appointed by the National Research Council to organize and develop the symposium program. The planning committee was chaired by Peter Sweatman of the University of Michigan Transportation Research Institute. Maxime Flament, ERTICO-ITS Europe, served as vice chair. Committee members provided expertise in vehicle technologies, intelligent transportation systems, human factors, traffic operations, and public policy. The planning committee was responsible for organizing the symposium, identifying speakers, commissioning two white papers, and developing three use case scenarios on road transport automation to facilitate discussion. The white papers and the use case scenarios are provided as appendixes. New readers may find it advantageous to review these appendixes first to more fully understand the discussion in the breakout groups.

The three use case scenarios—freeway platooning, automated city center, and urban chauffeur—were developed by the planning committee to help frame discussions in the breakout groups. The scenarios highlight potential applications at different levels of automation that serve different market segments and user groups and that reflect different implementation time frames. The breakout group discussions focused on identifying issues, opportunities, and research topics appropriate for EU-U.S. collaboration.

The symposium's interactive format enabled ongoing input from the assembled experts. The symposium began with a keynote presentation on realizing self-driving cars by Chris Urmson from Google. Summaries of the white papers on road transport automation as a public–private enterprise and as a societal change agent were also presented in the opening session. The format for the presentation of the three use case scenarios and the breakout group discussions was also highlighted.

A similar format was followed for each of the use case scenarios. First, members of the planning committee summarized the key elements of the scenario. Second, participants broke into groups to discuss opportunities, barriers, and potential research topics. Third, the reporters for each breakout group summarized the key discussion points in a general session. The symposium concluded with closing comments from EU, U.S. Department of Transportation, and TRB representatives.

This report prepared by Katherine F. Turnbull, Texas A&M Transportation Institute, the symposium rapporteur, is a compilation of the presentations and a factual summary of the ensuing discussions at the event. The planning committee's role was limited to planning and convening the conference. The views contained in the report are those of individual symposium participants and do not necessarily represent the views of all participants, the planning committee, TRB, the European Commission, the U.S. Department of Transportation, or the National Research Council.

This report was reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise. 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: David Agnew of Continental Automotive Systems Inc., Myra Blanco of the Virginia Tech Transportation Institute, Greg Larson of the California Department of Transportation, and Tom Schaffnit of A2 Technology Management LLC. Although the reviewers provided many constructive comments and suggestions, they did not see the final draft of the symposium summary before its release.

The review of this summary was overseen by Henry G. Schwartz, Jr., consultant. Appointed by the National Research Council, he was responsible for making certain that an independent examination of this summary was performed in accordance with established procedures and that all review comments were carefully considered. Responsibility for the final content of this summary rests entirely with the authors and the institution.

Acronyms

ACC	adaptive cruise control
AdaptIVe	Automated Driving Applications and Technologies for Intelligent Vehicles
APM	automated people mover
AV	automated vehicle
AV-CV	automated vehicles and connected vehicles
CES	Consumer Electronics Show
ConOps	concept of operations
CV	connected vehicle
DARPA	Defense Advanced Research Projects Agency
DSRC	dedicated short-range communication
EC	European Commission
Euro NCAP	European New Car Assessment Program
FOT	field operations test
GNSS	global navigation satellite systems
HMI	human–machine interface
I2V	infrastructure-to-vehicle
iGAME	Interoperable GCDC (Grand Cooperative Driving Challenge) Automation Experience
ITS	intelligent transportation systems
MaaS	mobility as a service
NRC	National Research Council
OEM	original equipment manufacturer
SAE	Society of Automotive Engineers
SLAM	simultaneous localization and mapping
TEAADS	Test Environment for ADAS (Advanced Driver Assistance Systems) and Automated Driving Systems
TRB	Transportation Research Board
U.S. DOT	U.S. Department of Transportation
UNECE	United Nations Economic Commission for Europe
V2I	vehicle-to-infrastructure
V2V	vehicle-to-vehicle
V2X	vehicle-to-everything
VRU	vulnerable road user

Contents

Welcome and Introductory Remarks

Peter Sweatman of the University of Michigan Transportation Research Institute, Ann Arbor, Michigan, welcomed the participants to the symposium. He acknowledged the symposium sponsors—the Office of the Assistant Secretary for Research and Technology, U.S. Department of Transportation (DOT); the Directorate-General for Research and Innovation, European Commission; and the Transportation Research Board (TRB) of the National Academies[1]—and noted that the symposium was the third sponsored by the three organizations to enhance cooperation and coordination between the United States and the European Union. Sweatman suggested that the topic of road automation is of great interest to public agencies, the automotive industry, technology companies, and other diverse stakeholders.

Sweatman next recognized and thanked the symposium planning committee and acknowledged the special assistance of Planning Committee Co-Chair Maxime Flament of ERTICO-ITS Europe. He observed that the hard work of the committee members provided an excellent example of transatlantic cooperation and noted that the planning committee spent a lot of time developing the use case scenarios and the breakout group format to ensure a productive symposium. He also thanked the authors of the white papers, Richard Bishop of Bishop Consulting; Steve Shladover of the University of California, Berkeley; Oliver Carsten of the University of Leeds; and Risto Kulmala of the Finnish Transportation Agency. Sweatman recognized Katie Turnbull of the Texas A&M Transportation Institute, who would serve as the symposium rapporteur and complete the symposium proceedings, and Barbara Siegel, who would graphically record the symposium sessions. He praised the excellent support given by Monica Starnes of TRB and Frank Smit of the European Commission.

Sweatman stressed the importance of road transport automation on the efficient movement of people and goods. He noted the impacts of recent advancements in vehicle and information technologies. Sweatman challenged symposium participants to actively engage in discussions over the 2 days and to share their ideas on opportunities, challenges, and potential research topics associated with road transport automation.

Manuela Soares of the Directorate-General for Research and Innovation, European Commission, noted the importance of transatlantic communication and cooperation to address common transport challenges. She indicated that the first two symposiums had fostered increased dialog and collaboration between the partners and noted the mutual interest in road automation and the variety of activities under way in Europe and the United States.

Soares thanked Sweatman and the planning committee for their hard work in organizing the symposium. She remarked that the white papers provided excellent background information and that the use case scenarios set the

[1] On July 1, 2015, the official name of the National Academy of Sciences became the National Academies of Sciences, Engineering, and Medicine.

stage for the breakout group discussions. She stressed the importance of the breakout groups in identifying potential research topics for transatlantic collaboration. Soares noted that the results from the symposium will be of benefit in identifying themes for the 2016–2017 work program of the European Commission Directorate-General for Research and Innovation.

Soares recognized and thanked the other symposium sponsors, the U.S. DOT and TRB, and acknowledged the hard work of the European Commission and TRB staff. She noted the importance of the symposium in identifying opportunities for ongoing research collaboration and the importance of continuing the partnership to foster transatlantic cooperation and collaboration. Soares thanked the National Academies for hosting the symposium and encouraged participants to share their ideas for needed research and opportunities for collaboration.

Kevin Womack of the Office of the Assistant Secretary for Research and Technology, U.S. DOT, recognized the hard work of the planning committee and the support from U.S. DOT leadership and expressed appreciation to the authors of the white papers. Womack also thanked Monica Starnes of TRB and Frank Smit of the European Commission for their assistance to the planning committee and completing all the details for the symposium. He noted the effective use of conference calls and e-mail exchanges by the planning committee in developing the symposium format, the use case scenarios, the white papers, and the breakout discussion group process.

Womack recognized the leadership of Gregory Winfree, Assistant Secretary for Research and Technology, U.S. DOT, in developing the overall partnership and in organizing the symposium. He noted that Winfree's support had been instrumental in advancing the partnership between the U.S. DOT and the European Commission. He also indicated that the topic of automated roadways is of great interest to the assistant secretary and the department.

Womack stressed the importance of identifying opportunities for ongoing collaboration and thanked participants for taking time to attend the invitation-only symposium. He noted the interest of diverse public and private stakeholders in the topic and stressed the importance of the breakout groups in identifying transatlantic collaborative research needed to advance the organized, safe, and beneficial deployment of automated roadways.

Neil Pedersen, Executive Director, TRB, welcomed symposium participants to the recently renovated historic headquarters of the National Academies of Sciences (NAS). He suggested it was appropriate to be meeting in the NAS Building, as the interdisciplinary nature of road automation requires expertise from multiple fields, not just transportation. He noted that TRB is one of six divisions of the National Research Council, which is the operating arm of NAS, the National Academy of Engineering, and the Institute of Medicine.[2]

Pedersen noted that TRB was pleased to provide support for the three joint EU-U.S. symposia as part of the memorandum of understanding. He indicated that the symposia have been successful in facilitating information sharing and promoting collaborations and suggested that this symposium should generate more opportunities for research collaboration.

Pedersen highlighted TRB's interest in roadway automation and recent activities, including sessions at the TRB annual meeting, conferences, and research projects. He reported that automated vehicles (AV) and connected vehicles (CV) were the first hot topic identified by the TRB Executive Committee as part of its new strategic plan. Pedersen noted that TRB is becoming more strategic in identifying emerging and cross-cutting issues. He indicated that the results from the symposium will be of use in defining the TRB agenda on AV-CV as well as in identifying opportunities for EU-U.S. research collaboration.

Pedersen observed that TRB has had significant engagement in AV-CV research. He suggested that the widespread interest in the topic was evident in the 25 sessions at the 2015 TRB annual meeting that focused on AV-CV research, demonstrations and pilots, policy implications, and security concerns. One of the sessions featured a discussion of AV-CV activities and opportunities by the chief executive officers of several state departments of transportation. He also noted that at least 70 of the 220 TRB standing committees and task forces have indicated an interest in the topic.

Pedersen highlighted other upcoming activities, including the Automated Vehicles Symposium, sponsored by TRB and the Association for Unmanned Vehicle Systems International, on July 20 to 24, 2015, in Ann Arbor, Michigan. The University of Michigan Transportation Research Institute is a cosponsor of this conference. The December 2015 TRB university transportation center conference is also focusing on AV-CV research and deployment.

Pedersen highlighted examples of research studies under way through the Cooperative Research Programs. Current projects are examining the legal environment for driverless vehicles, the costs and benefits of public-sector deployment of vehicle-to-infrastructure (V2I) technologies, and the potential impacts of AVs on state and local transportation agencies. Other projects focus on the impacts of transit system regulations on AV-CV introduction and AV-CV applications in freight operations.

[2] On July 1, 2015, the Institute of Medicine became the National Academy of Medicine and joined the National Academy of Sciences and the National Academy of Engineering as the third academy overseeing the program units of the National Academies of Sciences, Engineering, and Medicine.

Pedersen acknowledged the work of the symposium planning committee. He noted that the use case scenarios introduced potential practical applications into the breakout group discussions. He suggested that thanks to the efforts of the planning committee and the sponsors, the symposium really focused on where hype meets reality and where vision and dreams meet practicality and implementation. Pedersen further suggested the need to focus discussions on the current state of the practice, which is quickly evolving, future directions and possibilities, and what can practically be implemented in the near term and the longer term.

In closing, Pedersen thanked the symposium sponsors: the European Commission and the U.S. DOT Office of the Assistant Secretary for Research and Technology. He encouraged active participation over the next 2 days, especially in identifying potential research topics for future EU-U.S. collaboration.

Opening Plenary Session

Chris Urmson, *Google, Mountain View, California, USA*
Richard Bishop, *Bishop Consulting, Granite, Maryland, USA*
Steven E. Shladover, *University of California, Berkeley, California, USA*
Oliver Carsten, *University of Leeds, Leeds, United Kingdom*
Risto Kulmala, *Finnish Transport Agency, Helsinki, Finland*
Maxime Flament, *ERTICO-ITS Europe, Brussels, Belgium*

Keynote Presentation: Realizing Self-Driving Cars

Chris Urmson

Chris Urmson discussed the work under way at Google related to self-driving cars. He described the interest and motivation at Google for self-driving vehicles, his background and interest in the area, and recent research and tests being conducted by Google.

Urmson suggested that the invention of the automobile by Carl Benz in 1885 was an amazing step forward for society, with a major impact on shaping cities, enabling interstate commerce, and providing mobility. He noted that the first public demonstration of the vehicle ended with Carl Benz crashing it into a wall. He commented that work has been under way to reduce vehicle crashes ever since. Urmson noted that the first crash was symptomatic of a much bigger problem today, with approximately 33,000 roadway fatalities annually in the United States and 1.2 million fatalities worldwide. To put these numbers into context, Urmson indicated that the 33,000 annual fatalities would equal a 737 airplane crashing 5 days a week (every workday). He noted that approximately 94% of these crashes are due to human error, which technology could help address.

Urmson noted that traffic congestion is an issue in all urban areas. He suggested that the road system has not kept pace with increases in vehicle miles traveled: between 1990 and 2010, vehicle miles traveled grew by 38%, while the road system grew by only 6%. He suggested that only about 8% of the freeway surface area is being used at maximum throughput. He noted that automation would allow for tighter vehicle spacing that potentially would double the maximum throughput.

Urmson described the human impact of traffic congestion. The average commute in the United States is 50 minutes per worker per day. Urmson noted that when this figure is multiplied by 120 million workers, approximately 6 billion minutes per day are wasted being stuck in traffic. He suggested that reducing the time people spend in traffic would increase productivity and reduce stress. He also noted that alternatives are needed for people who are unable to drive because of physical or financial limitations and observed that the aging of the Baby Boom generation will increase the number of individuals who need alternatives to driving. Urmson described a situation of a vision-impaired individual who has a 3-hour commute rather than a 30-minute commute because he is unable to drive. Urmson noted that his team's mission at Google is to improve people's lives by transforming mobility.

Urmson described his background working in vehicle automation, which began with participation in the Defense Advanced Research Project Agency (DARPA) Grand Challenge while he was in graduate school. The Grand Challenge was initiated in response to a congressional mandate that by 2015, one-third of all military ground vehicles would be unmanned. The goal was to advance the rate of technical progress with unmanned vehicles.

Urmson explained that the DARPA Grand Challenge was a race of vehicles operated completely autonomously across the desert from Los Angeles to Las Vegas, a distance of approximately 130 miles. He reported that the first year, Google's vehicle traveled 7 miles at peak speeds of 40 miles per hour. He noted that the second year, their vehicle and others completed the race. He described the 2007 DARPA Urban Challenge in which unmanned vehicles recognized and responded to four-way stops at intersections and self-parked. No additional challenges were held, and Urmson noted that the community of people participating in the challenges disbanded and moved on to other activities.

Urmson described Google's interest and work in the area. He noted that the self-driving car team was formed in 2009 with a focus on fielding the technology and having an impact on the world. The two initial goals were to operate self-driving vehicles 100,000 miles on public roads and 1,000 miles on roads with a lot of variation. One of these roads was the El Camino Real from San Jose to San Francisco, California, which has approximately 240 signalized intersections and changes from four lanes in each direction to one lane in each direction.

Urmson indicated that several technologies were developed during the initial 18-month project, including high-resolution maps. Core elements of these maps included a spatial point cloud derived from data captured by infrared lidar, elevation models that provided a three-dimensional shape of the world, and vector representations of where to expect lane markings, traffic signals, crosswalks, and other roadway elements. Urmson noted that these technologies are used to determine the location of the self-driving vehicles. He provided an example that illustrated the improved accuracy of the system as compared with GPS.

Urmson noted that the two goals were accomplished within an 18-month period, after which a decision was made to focus on the next phase of freeway driving. He indicated that the fleet of Prius self-driving vehicles was upgraded to a fleet of Lexus self-driving vehicles. After undergoing additional testing on freeways, these vehicles were made available for employees to use. (Urmson indicated that Google's practice is to involve employees in product testing.) Urmson noted that the response was very positive, with more than 100 employees using the self-driving vehicles on a daily basis to commute to work and to make other trips. He indicated that the employees loved the technology, even those who were skeptical at the beginning. He also noted that the employees, especially those with long commutes, reported feeling more energized after arriving home in the evening (as compared with their normal commute).

Urmson noted that part of the assessment focused on what was happening inside the vehicle, explaining that the Google team had anticipated that people might overtrust the technology. Examples of observed behavior included a driver leaning back so that other travelers would think that there was no one in the vehicle and a driver reaching into the back seat for a laptop to charge his phone. In noting that these were not desired behaviors, Urmson said that the Google team had three options at this point: launch the technology, spend time debugging drivers, or reevaluate the project goals in the context of the mission to "improve people's lives by transforming mobility."

Urmson said that after assessing the situation, the team concluded that people want technology that gets out of the way. He suggested that in-vehicle technology that lets people know when they are doing something incorrect is not getting out of the way. He also noted that such technology does not help provide mobility to individuals with special needs. Therefore, the team took a step back and refocused on vehicles that can drive everywhere. He illustrated the point with a photograph of an intersection in Mountain View that includes a traffic signal, an at-grade railroad crossing, and vehicles, bicyclists, and pedestrians moving in all directions. He explained that interpreting the motion of vehicles in this type of setting is much more difficult than driving on a freeway.

Urmson reported that the Google team also examined the in-vehicle experience for drivers and the vehicle hardware. He suggested that when there is an individual in a vehicle who is being counted on to take over the driving function, there is inherent redundancy in the human operator. He noted that when the vehicle is driving without an operator, the human redundancy is removed. As a result, redundancy has to be built into the electronics architecture, the actuation architecture, and the sensing architecture. He suggested that vehicles are designed around the driver and that therefore there is a lot more opportunity to be innovative when the car is driving.

Urmson discussed the prototype concept vehicle being developed by Google. He noted that the vehicle is limited to speeds up to 25 miles per hour, primarily for safety reasons, and that it is being designed to operate in all types of urban settings, with all the challenges involved in the urban environment. Urmson described the pyramid of protection Google is using in designing the vehicle. At the apex of the pyramid is the physical protection of the occupants. Elements of the vehicle include the frame, the wheels, the sensing components that allow it to perceive the world, the electronics and drive train, the electronic interfaces, the interior body, and the exterior crash surface.

Describing the power architecture of the vehicle, Urmson noted that while the power comes from the tractive motor, there are redundant power buses and batteries that allow the intelligent components to continue to function to drive the vehicle into a safe state if needed. The operation of the redundant power system and its ability to bring the vehicle to a safe condition were highlighted in a video. Urmson commented that the vehicle has 360-degree laser and radar coverage as well as camera coverage. He described a Google-developed laser that provides 200 meters of vision with a narrow, steerable field of view. He noted the system can detect both a cinder block 150 meters ahead of the vehicle and a bicyclist's arm gestures and react accordingly.

Urmson noted that one criticism of Google's vehicles has been the Velodyne laser system mounted on the roof, which costs approximately $75,000. He said that the Velodyne laser has been replaced with a laser developed in-house at a lower cost. Sensors are imbedded around the vehicle. He reported that in combination, these sensors provide short-, mid-, and long-range coverage and an unprecedented degree of perception capabilities.

Urmson illustrated the prototype vehicle self-driving around the Google test facility in California's Central Valley. He noted that the vehicle interacts with other vehicles, pedestrians, and bicyclists under daily traffic conditions. He described the process of establishing an initial position of the vehicle by using the map-matching algorithm to align the vehicle very precisely against the map. The vector representation of where lane markings, crosswalks, and other features are is layered on the vehicle. The real-time view from the vehicle is also layered on the maps. Urmson provided an example of the prototype vehicle detecting traffic cones blocking a lane and a green light at a traffic signal. He suggested that a system based on the current location of vehicles would not be very useful and said that Google is using a predictive model of where all vehicles are moving. The model tracks vehicles at 10 times per second or more. The trajectory the vehicle should follow is calculated and the other vehicles that will influence its speed are identified and tracked. The angle of the steering wheel, the speed, and the braking are calculated and set. He described a video highlighting the prototype vehicle traveling through an intersection.

Urmson noted that the prototype vehicle also has to be able to interact with vulnerable road users (VRUs), including pedestrians and bicyclists. He described video illustrating the prototype vehicle operating with bicycles in different situations and noted that with almost a million miles of testing, the vehicles have interacted with pedestrians, bicyclists, and other vehicles in numerous situations. That information is used to train classifiers to understand what the vehicles encounter and to build behavior predictions. Urmson presented some examples of the unique situations that the prototype vehicles have encountered, including a woman in an electric wheelchair chasing a duck in figure eights in the middle of the road. He noted that the prototype vehicle identifies situations that are anomalies and treats them with extra attention by slowing down. Other examples included both vehicles and bicyclists running red lights, vehicles changing lanes abruptly without signaling, and vehicles pulling into traffic unexpectedly. Urmson indicated that the prototype vehicles also must be able to recognize police, fire, and emergency medical services vehicles as well as school buses and public transit buses. He noted that these vehicles have special operating characteristics and requirements for other vehicles.

Urmson described Google's vision for the technology as helping people get from Point A to Point B and carry out their daily activities without driving. He showed a video of people riding in prototype vehicles and noted the reaction has been very positive, including among individuals who may not be considered early technology adopters. He suggested that while there is a broad question about societal acceptance of autonomous vehicles, widespread support might be an easier step than most people imagine.

In closing, Urmson raised some provocative ideas to help stimulate discussion at the symposium. The first idea focused on vehicle-to-vehicle (V2V) technology. He suggested that V2V communication is an incredible technology that offers amazing opportunities to share information between vehicles but that it should not be a required predecessor for fully self-driving vehicles. Rather, he said, V2V is a great technology to layer on top of the perception capabilities embedded in vehicles. He further suggested that potentially there can be different paths to realizing the same societal benefits. He commented that both V2V and automated vehicle (AV) technology paths have challenges. He suggested that working on all paths may provide the best approach.

Urmson's second idea focused on digital maps. He pointed out the benefits of maps, especially in assisting with a vehicle verification and validation process. He noted the large number of variables associated with the operation of self-driving vehicles. Maps, he said, provide extra information beyond what the vehicle can sense. He noted that maps also limit the operating environment, which constrains the verification and validation process to some extent.

Third, Urmson suggested that self-driving vehicles would not be realized in incremental stages or by moving up through the driver assistance system. He suggested that there is a chasm between driver assistance and self-driving vehicles, noting that part of the chasm related to responsibility. He commented that with a driver assistance system, there is a driver who is responsible for the operation of the vehicle. The vehicle may be assuming some of the lower-level controls, but the driver is monitoring the operation at all times. With a fully self-driven vehicle that would provide mobility to visually impaired individuals, the responsibility for safe operation rests with the vehicle. Urmson suggested the technology and the market pressure were very different for the two approaches. He suggested that market pressure would force driver assistance systems to be lower in cost and have better precision but not necessarily full recall, whereas self-driving vehicles would need to apply much higher precision and recall.

Urmson concluded by encouraging all groups to work together to make self-driving vehicles a reality. He noted that he would like to see self-driving vehicles available for his oldest son, especially given the high crash and fatality rates among teen drivers.

Presentation of White Paper 1: Road Transport Automation as a Public–Private Enterprise

Richard Bishop and Steven E. Shladover

Steven Shladover and Richard Bishop summarized White Paper 1, "Road Transport Automation as a Public–Private Enterprise," the full text of which is included in this volume as Appendix A. They discussed the diversity of automation concepts, the state of the art and state of the market, and technological maturity. They also described nontechnical issues, business models, and potential roles within the public and the private sectors and identified research topics for exploration through EU-U.S. collaboration.

Shladover noted that it is important to remember the diversity of automation concepts and suggested that this diversity may be an impediment to a mutual understanding of the concepts being discussed. He indicated that the white paper uses three dimensions to help in framing an understanding of specific applications: the goals to be served by the automation system, the roles of the driver and the automation system in the driving tasks, and the complexity of the operating environment.

Shladover indicated that road vehicle automation systems are not ends in and of themselves but are rather a means of satisfying individual and societal needs and goals. He reviewed possible direct user goals of automation systems, including improving driving comfort and convenience, freeing up time consumed by driving, and reducing vehicle user costs and travel times. Other possible system-level goals are improving traffic safety, reducing travel times, enhancing and broadening mobility options, and reducing traffic congestion in general. Additional potential goals are reducing energy use and pollutant emissions, making more efficient use of existing road infrastructure, and reducing the cost of future infrastructure and equipment. He noted that system designs will be different, depending on the project's goals.

Shladover highlighted the levels of automation definitions developed by the Society of Automotive Engineers (SAE) for SAE J3016. As presented in Table 1, the levels

TABLE 1 SAE J3016 Definitions of Levels of Automation

Level	Description	Definition	Execution of Steering, Acceleration, and Deceleration	Monitoring of Driving Environment	Fallback Performance of Dynamic Driving Task	System Capability (driving modes)
Human Driver Monitors the Driving Environment						
0	No automation	Full-time performance by the human driver of all aspects of the dynamic driving task, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	Not applicable
1	Driver assistance	Driving mode–specific execution by a driver assistance system of either steering or acceleration–deceleration that uses information about the driving environment and with the expectation that the human driver performs all remaining aspects of the dynamic driving task	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial automation	Driving mode–specific execution by one or more driver assistance systems of both steering and acceleration–deceleration that that uses information about the driving environment and with the expectation that the human driver performs all remaining aspects of the dynamic driving task	System	Human driver	Human driver	Some driving modes
Automated Driving System Monitors the Driving Environment						
3	Conditional automation	Driving mode–specific performance by an automated driving system of all aspects of the dynamic driving task with the expectation that the human driver will respond appropriately to a request to intervene	System	System	Human driver	Some driving modes
4	High automation	Driving mode–specific performance by an automated driving system of all aspects of the dynamic driving task even if a human driver does not respond appropriately to a request to intervene	System	System	System	Some driving modes
5	Full automation	Full-time performance by an automated driving system of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver	System	System	System	All driving modes

range from 0 (no automation) to 5 (full automation). He noted that the system takes on more of the driving responsibility at the higher levels of automation. He also discussed Table 2, which provides examples of systems and driver roles associated with different levels, and indicated that the Level 1 and 2 systems are currently commercially available. Shladover noted that the automated driving system, not the driver, monitors the driving environment at Levels 3, 4, and 5.

Shladover discussed the complexity of the operating environment. He indicated that the degree of segregation from other road users is critical in discriminating between the different systems. He noted it was important to remember that totally automated systems without drivers have been operating on exclusive guideways for decades. These systems are in operation at airports and in other areas.

Shladover noted that exclusive guideways, dedicated highway lanes, general limited-access highways, protected campuses, special-purpose pathways, pedestrian zones, and urban streets all have different degrees of separation. He indicated that the complexity of traffic, including the speed, density, and mix of users, also influences the complexity of the operating environment. Weather and lighting conditions, the availability of infrastructure-to-vehicle (I2V) and V2V data, and the standardization of signage and pavement markings represent additional influencing factors.

Bishop described the state of the art in the development of automated driving systems. He noted that examples of highway operation include prototype vehicles driving in lane, changing lanes, and merging. He also noted that there are examples of prototype vehicles driving on a wide range of city streets and navigating signalized intersections, roundabouts, and other elements. He indicated that key technology elements of these prototype vehicles include sensors (radar, stereo and mono cameras, lidar), data-processing systems, and dynamic maps.

Bishop suggested that at Level 4, automated chauffeuring is viewed as a natural evolution by some original equipment manufacturers (OEMs) and is being pursued by Google, Uber, and others. He noted that these efforts focus on street-level automated driving at low speeds and in limited geographic areas. He also indicated that prototypes of Level 3 automated truck platooning have been demonstrated by some OEMs with a focus on long-haul freight transport on well-structured highways.

Bishop discussed the state-of-the-market section in the white paper. He noted that active safety systems, which form the technological foundation for AVs, are currently available on many vehicle models in Europe and North America. He said that examples of Level 2 highway use systems currently available on a few models include simultaneous adaptive cruise control (ACC) and lane centering at highway speeds on well-structured highways with limited curvature. He described Traffic Jam Assist, which provides low-speed automated lateral and longitudinal control. With the Traffic Jam Assist system, drivers are instructed to keep their hands on the steering wheel, or the system disables the feature. With combined ACC and lane centering, some manufacturers require hands on the wheel while others do not. He stressed that this will be an important factor to monitor as products evolve, one that could have safety implications.

Bishop noted that Level 2 and 3 highway use systems are anticipated to be available by the end of the decade. He noted that these systems will have full speed range and will be capable of accommodating a full range of normal highway curvatures. He further indicated that some approaches will actively monitor the driver's attention and gaze and provide a warning if the driver does not have his or her eyes on the road. According to Bishop, some systems will simply drive the vehicle in a particular lane, while others will also make lane changes as needed. He noted that OEM announcements and dates for these systems include Toyota by middecade, Audi and GM by 2016, Nissan by 2018, and BMW by 2020. He also described aftermarket systems, including those being developed by small start-up companies.

Bishop described the Volvo Drive Me project, which is a Level 3 highway use field test involving 100 vehi-

TABLE 2 Examples of Systems at Each Automation Level

Level	Example System	Driver Role
1	Adaptive cruise control or lane-keeping assistance	Must drive "other" function and monitor driving environment.
2	Adaptive cruise control and lane-keeping assistance Traffic Jam Assist (Mercedes)	Must monitor driving environment. (System nags driver to try to ensure monitoring.)
3	Traffic Jam Pilot Automated parking	May read a book, text, or web surf but be prepared to intervene when needed.
4	Highway driving pilot Closed campus driverless shuttle Driverless valet parking in garage	May sleep; system can revert to minimum risk condition if needed.
5	Automated taxi (even for children) Car share repositioning system	No driving needed.

cles for use by the public on limited to specific roads in Gothenburg, Sweden. The system is anticipated to be operational by 2017. Bishop indicated that automated valet parking, despite being a Level 4 system, will come to market quickly because vehicles are within a parking lot or parking garage and are traveling at low speeds. He noted that Level 4 automated chauffeuring is being tested in Europe and that Google has indicated that pilot testing of the system will begin this year.

Bishop observed that truck platooning has received a lot of attention recently. He noted that truck platooning, which involves longitudinal control only, is a Level 1 system. The combination of radar and V2V enables vehicles to follow at less than 100 feet. He suggested that the vehicle drafting and aerodynamics provided by truck platooning results in substantial fuel economy benefits that make it compelling to the trucking industry. He noted that commercial offerings are expected within the next 2 to 3 years, with pilot testing in the U.S. likely to begin this year.

In summarizing the state of the market, Bishop suggested there were two parallel paths: everything somewhere and something everywhere. He credited Bryant Walker Smith for these terms. Bishop described the everything somewhere path as full automation in some applications in some locations. The Google car and the CityMobil projects are examples of this path, he suggested. Bishop noted that this path may focus on fleet operations, which involve frequent servicing and testing to ensure safe operation. He suggested that everything somewhere is a viable path, although it may be limited geographically. The second path, something everywhere, involves a more limited level of functional automation that can be used everywhere. He suggested that this path follows the classic incremental approach whereby systems are brought to market on private vehicles capable of operating on any road, with no geographical limitations.

Bishop noted that the importance of infrastructure support for automation product introduction is under debate. He said that while some feel that product introductions will proceed without requiring infrastructure support, clearly some level of infrastructure support will be essential to gain transportation benefits. He described the various types of support that may be needed, including I2V and V2V real-time data, physical protection from hazards, and digital infrastructure for static and dynamic data. Other types of support include sensor-friendly signage and markings, better lighting, and higher maintenance standards.

Bishop highlighted the scenarios for providing support discussed in the white paper. One scenario focuses on private providers with little support from public agencies. In a second scenario, the automobile industry and users push public agencies to prioritize this support for different applications. In a third scenario, public agencies provide support proactively on the basis of perceived public benefits.

Shladover discussed the diverse stakeholders involved in developing, testing, and deploying AV-CV. These stakeholders include vehicle manufacturers and suppliers, other technology industry companies, regulators and public authorities, infrastructure and road operators, and public transport operators. Other stakeholders are the goods movement industry, users and private drivers, VRUs, and shared vehicle and fleet operators. A final set of stakeholders identified in the white paper includes the insurance industry, big data service providers, research and academic institutions, and the legal profession. Shladover noted that the white paper describes the different types of issues relevant to the various stakeholders.

Shladover indicated that the white paper examines the advances in technology that will be needed to achieve Level 3 and above applications, and research opportunities to address these challenges. The white paper presents these technology challenges by degree of difficulty. He noted that the first category included technologies that need some development but no fundamental breakthroughs. He indicated that technologies included in this category were wireless communications and localization. He noted that the next level of more challenging categories address a series of human factors and driver interface challenges, including safe control transitions, deterring misuse and abuse, encouraging vigilance, and facilitating correct mental models of system behavior. The white paper also addresses cybersecurity, but Shladover noted that cybersecurity is an issue for any modern vehicle with on-board electronics and is not unique to AV-CV.

Shladover described some of the even more challenging issues, including fault detection, identification, and accommodation within cost constraints. He suggested that ethical considerations in computer control represented another challenging issue. Environment perception and threat assessment, including minimizing false positives and false negatives under diverse conditions with affordable sensors, represent another challenging issue identified in the white paper. Software safety, including the designing, developing, verifying, and validating of complex software systems to a higher level of safety, was the final and most challenging technology issue discussed by Shladover. He suggested that research is needed on the appropriate mix of formal methods, simulation, and testing to address these topics.

Shladover highlighted some of the nontechnological issues associated with AV-CV deployment identified in the white paper. Examples included public policy, legal issues, vehicle certification and licensing, public acceptance, insurance, and assessment of benefits and impacts.

He noted that these issues may be more challenging to address on a transatlantic basis because of the differences in public institutions and public policies. He suggested that there is a need to work harder to identify common lessons from addressing nontechnical issues in the European Union and the United States.

Shladover suggested that business models and public–private roles may also be different between the European Union and the United States because of their different institutional structures. He described the standard approach of privately owned vehicles operating on public infrastructure with limited interaction. Shladover indicated that automation may have synergistic benefits from closer coupling of vehicles and infrastructure, which might open up integrated business models with common ownership of vehicles and infrastructure providing transportation as a service. He suggested that this model mirrors the railroad industry. He reviewed the financing options examined in the white paper, including joint public–private financing, road user charges, new public–private partnerships, and investments from the information technology industry.

Shladover indicated that the white paper identifies a wide range of research needs to address technology issues and nontechnical concerns. He highlighted a few of the nontechnical research issues, including possible changes in driver licensing and testing requirements, potential regulations of AVs at the national and state levels, and the need for more uniform standards for roadways and roadside infrastructure.

In closing, Shladover described some of the major unresolved questions. He noted that some of the questions are philosophical, while research could help address other questions, including the following:

- How much support and cooperation do AVs need from roadway infrastructure and other vehicles?
- How big a public sector role should be provided in infrastructure support?
- Do higher levels of automation require fundamental breakthroughs in some technological fields?
- What roles should national, regional, and state governments play in determining whether an AV is safe enough for public use?
- How safe is safe enough?
- How can an AV be reliably determined to meet any specific target safety level?
- Should AVs be required to inhibit abuse and misuse by drivers?
- Are new public–private business models needed for higher levels of automation?
- How will AVs change public transport services, and will societal goals for mobility be enhanced or degraded?
- What will be the net impacts on vehicle miles traveled, energy, and the environment?

Presentation of White Paper 2: Road Transport Automation as a Societal Change Agent

Oliver Carsten and Risto Kulmala

Oliver Carsten and Risto Kulmala summarized White Paper 2, "Road Transport Automation as a Societal Change Agent," the full text of which is included in this volume as Appendix B. They described the potential benefits of road transport automation to individuals and to society. They also discussed the potential short- and long-term costs to individuals, vehicle owners, infrastructure owners and operators, service providers, the automotive industry, and authorities.

Carsten noted that the initial focus of the white paper was on the potential socioeconomic impacts of automation and the groups receiving the benefits and bearing the costs. He indicated that the white paper was expanded to include broader societal implications of automation.

Carsten presented photographs from the 1950s and from 2015 illustrating the same concept of self-driving automobiles. He noted that in both cases, the vehicles were envisioned to travel at high speeds on roadways without any driver interaction, allowing drivers and passengers to engage in infotainment. Carsten cited vehicles from Daimler and Google as current examples of this approach, along with the CityMobil2 urban transit vehicles and the truck platooning operations. He noted that the white paper examined two time frames: the incremental near and medium term, or the next 5 to 10 years, and the long term or transformational period.

Carsten reviewed the potential individual benefits of road transport automation. He suggested that access to infotainment appears to represent one of the major benefits. He noted that the potential to work in a vehicle rather than drive has a major impact on both the value and the cost of travel time. He indicated that in the United Kingdom, an individual spends approximately 235 hours a year driving. He noted that road transport automation has the potential to result in major lifestyle changes that will improve the quality of life. He also noted that long-distance commuting by private vehicles may become more palatable to individuals and thereby make possible a wider choice of residency location. Other potential benefits highlighted in the white paper included the reduced risk of fines related to compliance with traffic laws and regulations, increased comfort in driving, potential cost savings from increased safety and reduced insurance premiums, and accessibility of driving for elderly individuals.

Carsten suggested that technical equipment on Level 3 and 4 vehicles would provide substantial safety benefits even when used in manual driving and at Levels 1 and 2. The white paper examines estimates of reductions in crashes and fatalities resulting from automated road transport. One source, eIMPACT, estimated that the benefits could be on the order of a 50% reduction in fatalities. Roadway efficiency and capacity should also improve, especially with cooperative intelligent transportation systems, which should increase vehicle throughput. Carsten also suggested that there could be negative consequences for nonautomated vehicles and other road users. For example, long truck platoons could form moving roadblocks for other users. In addition, there is the potential in urban areas for pedestrians and cyclists to lose road space. He noted that this issue came up in the CityMobil2 test in La Rochelle, France, as bicyclists lost road space for the track of the automated bus. He suggested that with regulation, cooperative intelligent transportation systems could help to address problems of interaction between AVs and manual vehicles.

Carsten reviewed some of the environmental benefits of road transport automation outlined in the white paper. He noted that vehicles operating under automated control should be more fuel-efficient, which will reduce energy consumption and emissions. He also noted that AVs could encourage more long-distance driving, more long-distance commuting, and more urban sprawl.

Kulmala discussed the potential costs to different groups from road transport automation. He suggested the costs to individuals may include special driver training and road user education and special licenses or permits to operate an AV. He suggested that the costs of owning and maintaining an AV would be higher than those for conventional manually driven vehicles and reported that today's technology packages for Level 2 automation were approximately $3,000. He noted that the higher degree of redundancy for safety-critical systems and components in AVs increases their costs. He also discussed the willingness of vehicle owners to pay for driver support systems and for self-driving capabilities.

Kulmala described some of the potential costs for infrastructure owners and operators. He suggested that special lanes or roads reserved for AVs might be needed if a critical mass of AVs existed. He noted that repurposing or redesignating existing dedicated lanes could also occur and that road markings and traffic signs would need to be harmonized, visible, and in good condition. Kulmala used Figure 1 to illustrate the variety of signs for pedestrian crossings in use today. He also noted that winter maintenance is a concern in many countries and regions. Other possible costs for infrastructure owners and operators highlighted by Kulmala included roadside features such as landmarks, posts, and poles to facilitate automated driving in adverse weather and on private roads. He indicated that the availability of infrastructure for I2V and vehicle-to-infrastructure (V2I) communications, including dedicated short-range communication and cellular communication, may influence costs for operators. He further suggested that establishing a system for recovering costs through taxes, road user charges, or usage fees may be needed.

Kulmala suggested that one of the key costs for service providers was digital maps with sufficient quality for self-localization and environment interpretation. He noted that local dynamic maps are needed to collect information for vehicle decision making and indicated that additional sensors may also be needed to provide an electronic horizon. He described the need for data on basic road features as well as road malformations such as potholes and ruts. Kulmala discussed the need for

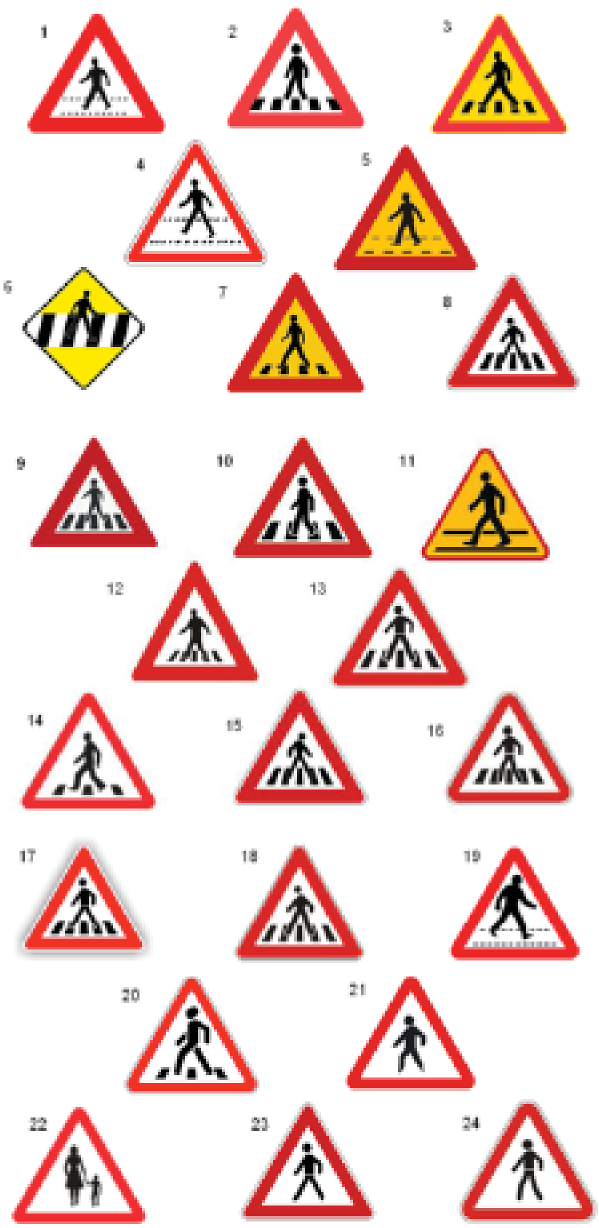

FIGURE 1 Examples of "Pedestrian Crossing" signs. [SOURCE: VRUITS (Improving the Safety and Mobility of Vulnerable Road Users Through ITS Applications), 2014.]

high-quality, real-time traffic information, especially for events, incidents, and congestion.

In describing the potential impacts on the automotive industry, Carsten noted that the costs associated with vehicle manufacturing may increase as a result of the complexity of the basic elements of automated driving. Examples of these elements include extended environmental sensing, accurate positioning, vehicle-to-everything (V2X) connectivity, the need to preserve driver and occupant privacy, and the need to ensure security. He suggested that these costs may decrease over time with the mass production of AVs. He further suggested that there may be additional costs related to standardization, training vehicle dealers, and vehicle servicing. Carsten noted that AVs are complex and may utilize proprietary technology. Finally, he suggested that insurance-related costs are likely to be affected if liability for vehicle operation at higher levels of automation is transferred from the driver to the vehicle manufacturer.

Kulmala described possible costs to authorities, including the need to establish regulations concerning AVs. He suggested that this process would require resources to conduct needed research, examine cross-border harmonization, and develop needed regulations. He noted that there may be a shift in the liability of stakeholders in the case of crashes. He commented that topics to be examined in this area included product liability and liability defenses; contributory negligence; misuse of a vehicle; self-certification processes by the vehicle industry, including tests; and use of event data recorders. Other topics included data and privacy protection and ownership of and the right to use the data produced by AVs. Kulmala noted that theft and security measures will also be required to prevent vehicle theft and hacking, just as with non-AVs. Other items that might increase costs for authorities included certification and roadworthiness testing, the need for standardization of vehicle performance (acceleration, braking, time headway, and response lag), as well as methods of informing the driver to take control back from the vehicle. He suggested that there may be a need for a global agreement on infrastructure requirements.

Carsten discussed some of the long-term benefits associated with AVs. He noted the transformational potential of automated driving as a new mode of transport and suggested that AVs could be as revolutionary as the introduction of the automobile at the turn of the 20th century. He suggested that AVs have the potential to reduce individual vehicle use and increase ridesharing. Carsten noted that issues associated with personal security will need to be addressed. He commented that if travel in AVs is too convenient, the use of AVs could be partly at the expense of walking and cycling. He also suggested that AVs could have a large impact on logistics, including the potential for last-mile delivery, and that AVs may have positive and negative effects on employment, especially for truck, bus, delivery, and taxi drivers. Other positive impacts Carsten noted were the need for less space in which to park vehicles and increased access to employment for individuals who currently do not have a vehicle available. He suggested that potential negative impacts include increases in long-distance commuting and residential dispersion and increases in road freight while other freight modes were used less.

The benefits of AVs for individuals highlighted by Carsten included mobility for those who do not have a vehicle or a driving license as well as for those with physical impairments. Other individual benefits included increased efficiency in time gained from vehicles that park themselves and more affordable mobility resulting from lower levels of vehicle ownership and increased subscriptions to vehicle sharing or ridesharing.

Addressing the potential social benefits associated with AVs, Carsten cited the use of travel time for work and entertainment, which has implications for the value of travel time used to calculate the benefit–cost analysis of transport-related investments. The potential safety benefits would include the replacement of the driver with more reliable systems that would not be subject to alcohol abuse, fatigue, inattention, or distraction. Carsten further suggested that AVs would comply with traffic regulations and that I2V and V2V would increase the safety of driving in conditions of poor visibility.

Another potential social benefit discussed by Carsten was a substantial increase in roadway efficiency and capacity, depending on the extent of continued manual driving, which would require the need for management of the interaction of manual vehicles and AVs. He suggested that narrower dedicated lanes for AVs could lead to increases in capacity and commented that consideration may need to be given to how motorcycles would be accommodated on these lanes. Carsten also noted that AV applications might reduce public transport costs. He cited reductions in energy consumption (as a result of smoother driving and fewer incidents), reductions in vehicle emissions, and reductions in land needed for parking as possible environmental benefits that would derive from AVs.

Kulmala described possible longer-term costs. He noted that public information campaigns and awareness measures may be needed both for individuals utilizing AVs and for drivers of nonautomated vehicles, cyclists, pedestrians, and other travelers. He commented that developing an awareness of the behavior of AVs among other users would be important.

Kulmala indicated that the cost of fully automated vehicles is likely to be higher than that of nonautomated vehicles, but that if vehicle sharing or leasing is used, individuals may not need to purchase vehicles. As a result, actual use costs may be lower. He suggested that in the long term, if all vehicles were fully automated, they might be lighter and simpler than today's vehicle, which would result in lower costs.

Kulmala noted that the potential long-term costs to infrastructure owners and operators would be higher owing to more widespread AV applications. He suggested that changes in road paving and repaving practices, including the use of higher-quality and more expensive aggregate and new paving equipment, might be needed because of narrower lanes and stricter lane keeping. He also noted that AVs may require higher asset management standards related to road pavement conditions, signs, and markings and suggested that consideration may also need to be given to other changes in road infrastructure, observing that, for AVs, roundabouts are more efficient than traffic signals. Restriction of urban zones to automated public transport, pedestrians, and bicyclists may also need to be considered.

Kulmala suggested that higher-quality maps and services may be needed in the long term, which will increase costs to service providers. Further, he noted that there will still be a need for towing and roadside breakdown services. He commented that higher service levels would likely be needed for AVs, but that V2X and accurate positioning data would assist in helping provide roadside services.

Kulmala suggested that AVs might lead to major changes in the automotive industry over the long term. He commented that, on the one hand, full road transport automation might result in fewer vehicles in use and thus reduce the automotive industry's profits, but on the other hand, more intensive vehicle use and the servicing of AVs might result in increased profits. He suggested that relationships with service providers may become more important in the future than relationships with individuals, and that the industry focus may change from vehicle manufacturers to the service providers.

Kulmala suggested that the long-term costs for authorities were similar to the near-term costs, focusing on regulations, liability, and safety and security. He noted that further consideration may need to be given to ensuring that driverless vehicles are not used to commit crimes or as weapons of destruction.

In concluding, Carsten noted that common themes in the white paper included the substantial requirements that AVs would place on road operators and the need for regulations governing the design, operation, and use of AVs. He suggested that the benefits to individuals and to society would be substantially increased with cooperative intelligent transportation systems and with increased management of the road system. Topics for further discussion, he said, include the potential for more sharing of vehicles in Europe but more private ownership of vehicles in the United States and the impacts of road transport automation on land use and development patterns.

Setting the Stage for the Symposium

Maxime Flament

Maxime Flament, vice chair of the symposium planning committee, introduced and thanked the members of the symposium planning committee, whose names are listed in Table 3. He also thanked the authors of the white papers and the staff from the U.S. Department of Transportation, the European Commission, and TRB for their assistance in organizing the symposium.

Flament noted that the planning committee spent a good deal of time at its first meeting discussing the focus and mission for the symposium. He indicated that the title of the symposium, "Towards Road Transport Automation: Opportunities in Public–Private Collaboration," reflects the results of this discussion. The planning committee felt there was a need to better understand the roles and responsibilities of the private and public sectors in advancing road transport automation and to identify areas for EU-U.S. collaboration.

Flament reviewed the mission statement for the symposium developed by the planning committee: "What are the **complementary roles and responsibilities** of the actors in a **public–private ecosystem** needed to drive the **evolution of automated vehicles** toward a 21st century mobility system (**integrating and optimizing vehicle, user, and infrastructure**)?" He noted that the words in bold reflect the key elements of the mission statement.

Flament reviewed the desired outcomes for the symposium: first, to foster transatlantic partnerships and future collaboration on research areas of mutual interest and, second, to draw out research challenges worthy of international collaboration. He noted that these potential research topics could be advanced by the symposium sponsors and other groups, including the U.S. Department of Transportation's Intelligent Transportation Systems Joint Program Office, the National Cooperative Highway Research Program, and the European Commission.

Flament discussed the three axes of the symposium: the constituencies (he observed that the symposium participants represented a mix of public- and private-sector

TABLE 3 Symposium Planning Committee

United States	European Union
Peter Sweatman, *University of Michigan Transportation Research Institute, Chair*	Maxime Flament, *ERTICO-ITS Europe, Vice Chair*
David Agnew, *Continental Automotive NA*	Roberto Arditi, *SINA Group*
Robert Denaro, *ITS Consultant*	Aria Etemad, *Volkswagen AG*
Ginger Goodin, *Texas A&M Transportation Institute*	Natasha Merat, *University of Leeds*

TABLE 4 Symposium Constituencies

Constituency	Number of Participants
Automotive companies	8
Public authorities	5
Infrastructure, road operators	6
Public transport	3
Goods transport	3
Users, drivers, vulnerable road users	2
Shared vehicles and fleets	1
Insurers	2
Service providers	4
Research	12
Legal	2

constituencies, as illustrated in Table 4), the key topics (the subject of the white papers), and the use case scenarios that would serve as the basis for the breakout groups. He noted that key topics of discussion in each of the use cases focused on technology, legal issues, business models, and security. Other topics included human factors, policy making, testing, and user acceptance.

Flament discussed the three use case scenarios, including the basic components presented in Table 5:

Use Case Scenario 1. Freeway Platooning: Moderately Automated Freeway Operation,

Use Case Scenario 2. Automated City Center: Highly Automated Urban Operation, and

Use Case Scenario 3. Urban Chauffeur: Fully Automated Tailored Mobility Service.

He noted that the use cases had been distributed to the participants prior to the meeting and described the different characteristics (level of automation, speed, need for dedicated space, public or private lead, and project examples) associated with each use case. Flament explained that the use case scenarios were developed by the planning committee to highlight potential applications at different levels of automation that serve different markets and use groups and that reflect different time frames for implementation.

Flament described the use case scenario breakout group process illustrated in Figure 2 and the logistics for the breakout sessions. Each scenario would be presented in a plenary session by the planning committee champions. The symposium participants would then convene in their assigned breakout groups for 70 minutes. There were six groups, each of which contained between eight and 10 participants representing a mix of EU and U.S. attendees and a balance of constituencies. Each breakout group had a facilitator and a recorder. Within their groups, the participants would review the use case scenario and discuss the opportunities created for different constituents and the barriers limiting deployment. Opportunities for collaborative EU-U.S. research to address the barriers and advance deployment would be identified and discussed. After the breakout group discussions, the participants would reconvene in a plenary session to hear the facilitators and recorders report on the barriers, opportunities, and EU-U.S. collaborative research topics discussed by each group. Flament noted that the composition of the breakout groups was different for each of the three use case scenarios to provide opportunities for interaction with different symposium participants.

TABLE 5 Characteristics of Use Case Scenarios

Use Case	Level of Automation (SAE)	Speed (mph)	Dedicated Space	Private or Public	Examples Available Now (Projects)	Interaction with Infrastructure[a]
1. Freeway Platooning	2–3	High (>70)	Possibly both	Both	Sartre, Peloton	3
2. Automated City Center	3–4	Low (10–40)	No	Both	AdaptIVe	4
3. Urban Chauffeur	4	Low (<30)	Both	Public	Google, CityMobil2	5

[a]1 = low, 5 = high.

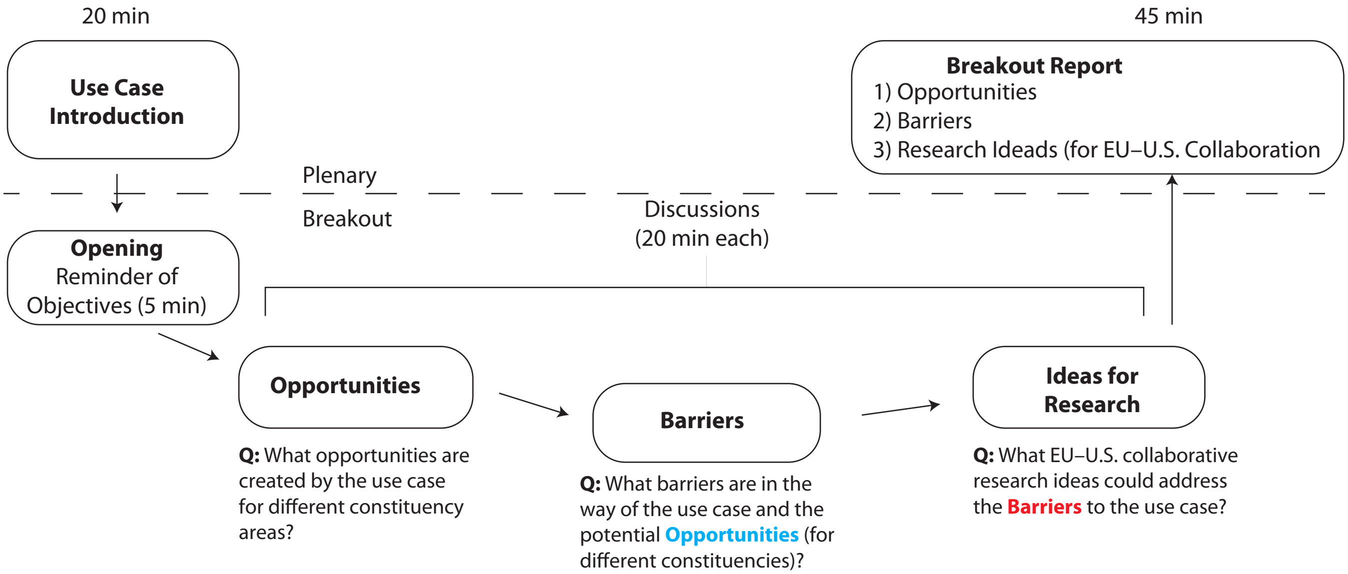

FIGURE 2 Process for use case scenario breakout groups.

USE CASE SCENARIO 1

Freeway Platooning

Moderately Automated Freeway Operation

Robert Denaro, *ITS Consultant, Long Grove, Illinois, USA*
Roberto Arditi, *SINA Group, Milan, Italy*
Oliver Carsten, *University of Leeds, Leeds, United Kingdom*
Richard Bishop, *Bishop Consulting, Granite, Maryland, USA*
Ginger Goodin, *Texas A&M Transportation Institute, College Station, Texas, USA*
Risto Kulmala, *Finnish Transport Agency, Helsinki, Finland*
Aria Etemad, *Volkswagen AG, Wolfsburg, Germany*
Steven E. Shladover, *University of California, Berkeley, Berkeley, California, USA*
David Agnew, *Continental Automotive NA, Auburn Hills, Michigan, USA*
Keir Fitch, *European Commission, Brussels, Belgium*
Natasha Merat, *University of Leeds, Leeds, United Kingdom*
Jane Lappin, *Volpe National Transportation Systems Center, U.S. Department of Transportation, Cambridge, Massachusetts, USA*

Presentation of Use Case Scenario 1, Freeway Platooning: Moderately Automated Freeway Operation

Robert Denaro and Roberto Arditi

Robert Denaro and Roberto Arditi, the planning committee champions for Use Case Scenario 1, described this scenario. They summarized the key characteristics of the scenario, the system concept, the operation, the user experience, and potential benefits. The full text of the use case is given in Appendix C.

Denaro reviewed the key characteristics of the freeway platooning use case scenario (Table 6). The freeway platooning scenario involved moderate automation at Levels 2 and 3 and high speeds. Dedicated lanes for the platooning vehicles could be used but were not required. Both the private and public sectors would likely be involved in the deployment of the scenario. The two examples of freeway platooning were the European Commission Safe Road Trains for the Environment (Sartre) project and the automated vehicle technology company Peloton, which specializes in technologies for commercial vehicle platooning. Denaro noted that the interaction with the infrastructure was medium. He suggested that feedback on these use case characteristics from the breakout groups would be beneficial.

Denaro expanded on some of the use case characteristics and parameters. The moderately automated scenario focused primarily on the platooning of commercial vehicles, but the ability of privately owned passenger vehicles to join a platoon was included in the use case. The operation would be subject to motor vehicle standards and road operator approval in the deployment areas. The use case focused on limited-access interurban highways and motorways, with the potential use for dedicated lanes and time restrictions.

Denaro highlighted the system concepts for freeway platooning, which included a lead commercial vehicle and trailing commercial and passenger vehicles. He noted that vehicle-to-vehicle communication was critical for this use case and commented that infrastructure and lane marking improvements would probably be needed to support this scenario. A method for automated entry and exit from a platoon would also be needed. The use parameters and operation could be weather sensitive, he noted.

The initial emergence of truck platoons could occur by 2018, Denaro said, with platoons of private passenger vehicles following at a later date. He suggested that the discussions in the breakout groups could assist in identifying research needed to implement freeway platooning over the next few years. Benefits could be

TABLE 6 Key Characteristics of Use Case 1: Freeway Platooning

Use Case	Level of Automation (SAE)	Speed (mph)	Dedicated Space	Private or Public	Examples Available Now (Projects)	Interaction with Infrastructure[a]
1. Freeway Platooning	2–3	High (>70)	Possibly both	Both	Sartre, Peloton	3
2. Automated City Center	3–4	Low (10–40)	No	Both	AdaptIVe	4
3. Urban Chauffeur	4	Low (<30)	Both	Public	Google, CityMobil2	5

[a]1 = low, 5 = high.

realized from reduced congestion, he noted, but infrastructure investments would probably be needed to fully realize these benefits.

Denaro said that it was anticipated that the lead commercial vehicle would be operated by a trained driver. The drivers in trailing vehicles could conduct tasks other than operating the vehicle. He indicated that while driverless trailing vehicles were not anticipated in the short term, they might be possible in the future. Denaro noted that the use case assumed platooning vehicles could operate at relatively high speeds, depending on local speed limits and conditions, and suggested that highway capacity could be increased by approximately 15%, with energy savings of 8% to 16% realized by the trailing vehicles.

This scenario would complement existing rail and metropolitan transport systems, Denaro suggested. Public agency investments in new signage, roadway markings, and perhaps dedicated lanes would be needed to support this scenario and to realize the full benefits. Connected vehicle technology, dedicated short-range communication, or, eventually, guaranteed low-latency device-to-device cellular connections would also be needed. Denaro noted that the interaction of platoon and nonplatoon vehicles would need to be managed.

Arditi described some of the anticipated benefits of truck platooning:

- Relaxing the hours of service limitations for operators of trailing vehicles might be considered.
- Platooning could make the commercial driving profession more attractive to new operators.
- Drivers in trailing vehicles could engage in other tasks.
- Vehicle platooning could increase capacity and reduce congestion on highways and motorways and improve safety.
- Truck platooning could provide for more efficient commercial shipping.

Arditi discussed potential benefits from this use case scenario to cities and authorities. In addition to reductions in energy consumption, vehicle emissions, and traffic congestion, these benefits include improvements in traffic flow management and safety and additional productive time for drivers. Passenger vehicle platooning might provide additional options for residential locations by allowing individuals to live farther from central cities or major employment concentrations. The possible limitations cited by Arditi were the need for infrastructure upgrades, public acceptance of platooning vehicles and mixed traffic, interjurisdictional standards, and security concerns.

The potential business-sector benefits identified by Arditi were reductions in the cost of operating commercial fleets, increased competiveness of commercial vehicles with other freight modes, and new business opportunities with passenger vehicles in platoons and with drivers in following vehicles. The possible limitations of freeway platooning included required investments by small fleet operators and passenger vehicle compatibility costs, he said.

Arditi concluded by presenting possible topics and questions for discussion in the breakout groups. He suggested that participants consider possible legal, technical, and economic issues that would prevent the operation of freeway platooning over the next 2 to 3 years. Other topics suggested for discussion included the role of research to facilitate the deployment of freeway platooning and possible transatlantic cooperation on research projects and field operations tests (FOTs).

Breakout Group A

Robert Denaro and Oliver Carsten

Oliver Carsten summarized the discussion of the use case scenario in Breakout Group A. He reported that participants discussed a wide range of potential opportunities and barriers associated with the freeway platooning scenario. The opportunities included improved energy efficiency, operator cost savings, driver health benefits, and increased roadway vehicle throughput. The barriers identified by different participants included driver training needs, operating in multiple jurisdictions, liability issues, adequate road capacity, the possible need for dedicated lanes, road surface quality, pavement markings, and funding for needed roadway improvements.

Carsten reported that the group identified 18 potential research topics, six of which the participants identified as important:

- FOTs with different applications of vehicle platooning in various settings to document business approaches, use of the platoons by commercial vehicles and other vehicles, and interaction with nonplatooning vehicles;
- The need for vehicle-to-infrastructure communication with vehicle platooning;
- Qualifications needed in the drivers of lead and trailing commercial vehicles and the appropriate training to meet these qualifications;
- Public acceptance of commercial vehicle platooning and private passenger vehicle platooning;
- Modeling of the interaction of commercial vehicle platoons with other vehicles to identify road infrastructure needs;
- Potential misuse and abuse involved in different vehicle platooning scenarios; and
- Risk scenarios, risk modeling, and reliability.

Breakout Group B

Roberto Arditi and Richard Bishop

Roberto Arditi summarized the discussion of the use case scenario in Breakout Group B. Examples of the opportunities the group saw in the freeway platooning scenario included the reduction of fuel use and of the costs of freight shipments, improvement of truck efficiency and safety, and better use of limited roadway capacity. Participants also suggested that private passenger vehicles could be allowed to join a platoon, perhaps for a distance-based fee, and that drivers in following vehicles could make productive use of their time. Possible barriers identified by some breakout group participants included hours of service regulations for truck drivers, regulations or guidelines for vehicle following distance, and liability if crashes occur. Other possible barriers suggested by participants were highway infrastructure improvements needed to accommodate vehicle platoons (e.g., longer ramps), safety and congestion concerns for nonplatooning vehicles, the impact of bad weather on platoons, and dealing with individual trucks. Participants also identified the impacts of multiple trucks arriving together at a destination, the need for additional training for truck drivers, security concerns, and unintended consequences as other potential barriers.

Arditi reported that the participants identified numerous research topics to help advance deployment of the freeway platooning scenario, many of which focused on operations, technology, infrastructure, and safety issues. Research topics suggested by different participants included

- Impacts of closely spaced truck platoons on pavements and bridges,
- Techniques to optimize platoon spacing dynamically to address any infrastructure concerns, and
- Optimal platoon length and operating strategies.

Research topics related to safety included

- Methods for safely stopping following vehicles when a driver does not respond to take over control,
- How to address individual vehicle failures in a platoon,
- Safety impacts on nonplatooning vehicles, and
- The need for special lanes for platooning vehicles.

Arditi noted that some participants suggested it would be beneficial for FOTs in the European Union and the United States to target these questions and issues.

Breakout Group C

Ginger Goodin and Risto Kulmala

Ginger Goodin summarized the discussion in Breakout Group C. She highlighted some of the opportunities associated with the freeway platooning scenario discussed by different participants, including reducing transport costs and fuel use, improving efficiencies and safety, creating new trucking and freight business models, and the potential for private passenger vehicles to join truck platoons. Goodin reported that of the numerous challenges and barriers identified by the group, many focused on operating elements, including platoon formation, operation of a platoon, and splitting or ending a platoon. Other related challenges were platoon lengths, requirements for lead and following drivers, and interaction with nonplatoon vehicles.

Goodin noted that participants discussed two phases for deployment of the truck platooning scenario—a transitional phase and full automation—and potential research topics associated with each. The participants suggested that more issues were likely to be encountered during the transitional phase. Research topics identified as important during this phase focused on the previously discussed challenges and barriers. Goodin highlighted two topics:

- Development of a concept of operations (ConOps) plan detailing the entry and exit of vehicles to a platoon, the length of a platoon, and the responsibilities of drivers in the lead truck and the following trucks and
- Development and testing of different business models, financing approaches, and user charges on rural and urban freeways.

Other research topics in the transitional phase suggested by participants included FOTs involving different potential operating strategies on roadways with different geometric characteristics, volumes, and speeds.

Participants suggested that sharing the results of these transatlantic FOTs would assist in making progress toward the second phase, full automation. Goodin reported that participants discussed the time frame for the transitional phase and that some suggested that the 3-year window presented in the use case was optimistic.

Breakout Group D

Aria Etemad and Steven E. Shladover

Steven Shladover summarized the discussion of the use case scenario in Breakout Group D. He reported that participants discussed several opportunities and barriers to deploying the freeway platooning use case. The opportunities focused on the ability of truck platooning to help address the shortage of commercial vehicle drivers, the commercial operator hours of service regulations, and traffic congestion. Other potential benefits identified by participants related to reducing truck operating costs, energy consumption, and emissions. Possible barriers discussed in the breakout group included acceptance by other road users, the potential of platoons to block freeway entry and exit ramps, allocation of liability among platoon members, and the need for changes in laws and regulations.

Shladover listed the five research topics suggested as beneficial by the different participants:

- Multistate or multinational demonstrations or FOTs—participants suggested that comparisons could be made between demonstrations in the European Union and the United States;
- The rules of the road for interaction with other roadway traffic;
- The value proposition from truck platooning for supply chain users, especially truck fleet operators; suggested elements of this analysis included identifying the economic costs and benefits to fleet operators, independent truckers, shippers, and the public;
- The impact of platooning on freeway operations and traffic flow (a somewhat related research need); and
- Potential driver issues and the impacts on operators of the lead truck and the following trucks; suggestions for the elements of this analysis included
  - Hours of service regulations for drivers of the lead and the following trucks,
  - Use of graduated licenses for operators of the following trucks, and
  - Impact on truck driver recruitment and retention.

Breakout Group E

David Agnew and Keir Fitch

Keir Fitch summarized the discussion of the use case scenario in Breakout Group E, noting that much of it focused on ensuring the safety of platooning and non-platooning vehicles. He reported that the participants identified the following opportunities associated with the freeway platooning scenario:

- Increasing truck fuel efficiency,
- Increasing roadway capacity at bottlenecks,
- Allowing drivers in following vehicles to perform other duties,
- Reviewing the hours of service regulations,
- Developing and using platoon time tables, and
- Allowing commercial vehicles, buses, and private passenger vehicles to join regularly scheduled platoons.

Fitch reported that the participants questioned whether vehicle platooning could work safely without Level 4 automation. Other possible barriers identified by some participants included liability issues in the case of a crash or a vehicle malfunction, the business case for investing in the needed automation, and the possible impact on commercial driver hours of service regulations.

Fitch described the two safety-related research topics discussed by individual participants:

- Standards for a human–machine interface to ensure that drivers of following vehicles were able to reassume the driving function and
- Minimum conditions or standards for safe operation of vehicle platoons, including providing for an automated safe stop.

A related research topic discussed by the participants was developing standards for platooning vehicles. Participants suggested that standards governing platooning vehicle brakes, power, data communication capabilities, and other factors were needed to ensure the safe and efficient operations of freeway vehicle platoons. Additional related research topics focused on

- Facilities and areas that would be safe for platooning vehicles and the decision-making process for approving routes,
- Hours of service regulations for drivers in following vehicles,
- Interaction of platooning and nonplatooning vehicles, and
- Guidelines and protocols.

Participants also suggested that a benefit–cost analysis was needed to determine the viability of the platooning use case.

Breakout Group F

Natasha Merat and Jane Lappin

Jane Lappin summarized the discussion of the use case scenario in Breakout Group F, noting that the group included a mix of representatives from the public and private sectors. Lappin reported that the group discussed the following opportunities associated with the freeway platooning scenario:

- Measurable economic benefits to commercial vehicle owners, operators, and shippers;
- The potential for passengers in private vehicles to experience faster and more relaxed travel by joining a platoon; and
- Transit buses joining a platoon or the organization of a platoon of buses.

Possible barriers discussed by participants included conflicts between platoon and nonplatoon vehicles, public acceptance, and infrastructure costs to accommodate platooning vehicles.

Lappin reported that the group identified 13 potential topics for research:

- FOTs and demonstrations to move research projects forward and determine how platooning systems work in a complex real-world context (many participants supported this topic);
- Algorithms for assigning truck platoons to routes so as to avoid the most congested urban freeways and motorways;
- Differences between the European Union and the United States related to commercial vehicle fleet technology, roadway network characteristics, laws, regulations, and other elements;
- The best policies in different platooning contexts and approaches to maximize societal benefits and limit negative societal impacts;
- Public acceptance of different lengths of truck platoons and various operating plans and examining the impact of the weight of truck platoons on bridges;
- The potential opportunity or business case for private investment in a roadway infrastructure for truck platooning;
- Potential liability issues in relation to multisubscriber platoons, including the assignment of liability for different types of situations;
- Overall ConOps for different truck and vehicle platooning scenarios;
- Examination of the need for public testing, verification, and validation of platooning approaches developed by the private sector and development of draft protocols and measures as needed;
- Platooning to enable innovative forms of public transport;
- Different approaches to truck platoon formation, including facilitated and spontaneous platoons;
- The benefits, limitations, and impacts of different approaches; and
- Development of shared platoon scenarios for future EU-U.S. research and FOTs.

Lapin noted that participants in the breakout group discussed that convening sectoral meetings and facilitating ongoing EU-U.S. interaction on topics of shared interest, such as the results of FOTs, would be beneficial.

Open Discussion

In the open session, individual symposium participants provided additional comments on the merits, opportunities, barriers, and potential research topics associated with the freeway platooning use case scenario. The following topics were discussed:

- Benefits to the trucking industry, including energy savings, increased fuel efficiency, reduced operating costs, and increased driver recruitment and retention;
- Possible impacts on driver hours of service, training and requirements for drivers in lead vehicles and following vehicles, and protocols for entering and leaving a platoon;
- The length of platoons, the speed of platooning vehicles, impacts on other road users, and private passenger vehicles joining a platoon;
- Adoption of platooning by the trucking industry;
- Vehicle equipment needs;

- Public acceptance;
- Safety concerns; and
- Safe-stop capabilities.

Several participants discussed sponsoring FOTs in the European Union and the United States to further define the business case for this scenario, to develop ConOps to address the questions raised during the discussion, and to build acceptance within the trucking industry and among other roadway users. Participants also suggested that FOTs could explore policy implications, alternative business models, the phasing of implementation, and whether to allow transit buses and private passenger vehicles in a platoon. Some participants suggested that sharing the results of these transatlantic FOTs would be beneficial to all groups. Participants also discussed possible time frames for freeway platooning, and some suggested that it was more a midterm than a short-term scenario.

USE CASE SCENARIO 2

Automated City Center

Highly Automated Urban Operation

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David Agnew, *Continental Automotive NA, Auburn Hills, Michigan, USA*
Keir Fitch, *European Commission, Brussels, Belgium*
Natasha Merat, *University of Leeds, Leeds, United Kingdom*
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Presentation of Use Case Scenario 2, Automated City Center: Highly Automated Urban Operation

Ginger Goodin and Aria Etemad

Ginger Goodin and Aria Etemad, the planning committee champions for Use Case Scenario 2, described this scenario. They summarized the key characteristics of the scenario, the context and time frame, and the sectoral perspectives. The full text of the use case is given in Appendix C.

Etemad reviewed Table 7 and the key characteristics of the automated city center use case scenario. The use case focused on vehicle automation for negotiating dense urban traffic and automated parking within a city center. Representing a high level of automation—Levels 3 and 4—the use case would allow drivers to transfer driving tasks to an automated system in a networked urban center.

Vehicles would operate at speeds of approximately 10 to 40 miles per hour. Dedicated space was not required, and it was anticipated that both the public and the private sectors would be involved in the implementation and operation of the use case. Etemad highlighted the Automated Driving Applications and Technologies for Intelligent Vehicles (AdaptIVe) project as one example of this approach. AdaptIVe is a large-scale, European Commission–sponsored, automated demonstration project in Europe involving 30 partners, including 11 automotive vehicle manufacturers and eight countries. It involves three different types of applications: automated parking, urban and city driving, and highway driving. The use case posits that the driver remains behind the wheel, with vehicles operating at low to medium speeds.

Etemad described the typical characteristics of city centers, which included high-density employment and residential development, closely spaced signalized and networked intersections, and parking structures. He also noted that the city center environment involved multiple street users, including automobiles, trucks and delivery vehicles, buses, motorcycles, bicycles, and pedestrians.

Etemad described the operating scenario developed by the symposium planning committee for the automated city center use case. Vehicle routing would be initiated when a driver entered a destination into the vehicle's navigation system via a connected app before a trip. The navigation system would offer the driver the most automated route. The driver would engage automation and would oversee operation of the vehicle. An urban traffic

TABLE 7 Key Characteristics of Use Case 2: Automated City Center

Use Case	Level of Automation (SAE)	Speed (mph)	Dedicated Space	Private or Public	Examples Available Now (Projects)	Interaction with Infrastructure[a]
1. Freeway Platooning	2–3	High (>70)	Possibly both	Both	Sartre, Peloton	3
2. Automated City Center	3–4	Low (10–40)	No	Both	AdaptIVe	4
3. Urban Chauffeur	4	Low (<30)	Both	Public	Google, CityMobil2	5

[a]1 = low, 5 = high.

management system would monitor the roadway network and communicate with the driver and other street users as needed, including asking the driver to resume the driving task when necessary. The vehicle would negotiate the optimal route. By means of the city parking database, the vehicle would be routed to available parking close to the requested destination. The driver would select a parking preference on the basis of information on parking availability and prices provided by the system. The space would be reserved and the vehicle would drive itself to the location. After the driver leaves the vehicle, it would self-park in a fully automated mode.

Goodin discussed the context and the possible time frame for the automated city center use case scenario. The logical targets for implementing the scenario were cities without extensive surface and underground passenger rail systems and smart cities with V2X connectivity. Goodin noted the importance of traffic management systems in this scenario. She also noted that the focus on safety was important for the use case.

The automated city center use case was envisioned as being enabled through public–private partnerships, Goodin reported. Vehicle mobility and parking could be packaged into a single service by new providers that would work with cities and other public agencies to develop, implement, and operate the service. With respect to timing, Goodin noted that Level 4 self-parking was anticipated to be available within the time frame of 2018 to 2020 and that Level 3 urban automation was estimated to be available after 2025.

Goodin described potential benefits and limitations of the automated urban operation scenario for users, cities, and businesses. Possible user benefits included improved safety, more relaxed driving, time savings from automated driving and parking, and reduced fuel consumption. Potential limitations focused on the availability of services and the costs associated with the system. Goodin noted that potential benefits focused on better performance of the transportation network, including optimized flow, reduced vehicle emissions, and reduced accidents. Optimized parking supply and revenue represented another potential benefit to cities. The potential liabilities to cities included increased vehicle miles traveled and the cost of infrastructure improvements.

Goodin suggested that from a business perspective, the automated city center scenario would provide opportunities for the integration of vehicle and infrastructure systems into a seamless and invisible underpinning to the effective movement of people and goods. The scenario also supports the smart city notion, which envisions investments in digital systems and infrastructure to connect transportation with other sectors, including energy, healthcare, and water and solid waste services to further economic and environmental objectives. She suggested that the integrated strategic urban transportation management described in the scenario would provide opportunities for private-sector involvement in data analytics for urban network optimization, modal integration, payment integration, and parking infrastructure operation.

Breakout Group A

Robert Denaro and Oliver Carsten

Oliver Carsten summarized the discussion of the use case scenario in Breakout Group A. He highlighted the general discussion on opportunities and barriers, noting that some participants discussed expanding the use case to include both cities of all sizes and urban freight applications. The participants also discussed the potential application of the scenario to valet parking of large- and medium-sized trucks. It was suggested that the highly automated urban operation scenario would also have environmental benefits. Potential barriers discussed by participants included the risk of collisions with vulnerable road users (VRUs), public acceptance, and the costs to cities.

Carsten listed the research topics identified by different breakout group participants:

- Potential urban freight applications, including
  - Valet parking or self-parking for commercial vehicles, enhancing the distribution of goods and
  - Technologies for supporting safe truck operations in urban areas;
- Development of a business case for cities that would highlight the benefits that could be realized by

participating in field operation tests (FOTs), demonstrations, and deployments;

- Explanation of the link to smart cities and environmentally friendly cities (suggested as part of developing a business case);
- Links to the quality of the urban environment;
- Approaches to maximize the environmental benefits of the automated city center scenario;
- Application of the automated city center scenario to enhance urban redevelopment;
- Consumer attitudes and acceptance;
- Interaction with other road users and possible safety concerns;
- Methods to increase road efficiency and road capacity; and
- Development of a phased implementation approach that would consider the benefits to different users, synergies with other use cases and applications, and funding methods, including the potential for collecting fees and the qualification of user benefits.

Breakout Group B

Roberto Arditi and Richard Bishop

Richard Bishop summarized the discussion of the use case scenario in Breakout Group B, noting that participants discussed numerous potential opportunities and barriers. Examples of opportunities cited by participants included improving the efficiency of the urban transport system, the environment of cities, and safety. Bishop noted that participants identified several legal issues as possible barriers.

Bishop listed the 12 research topics discussed by the participants:

- A common framework for assessing potential liability in vehicle crashes occurring in an automated mode;
- A road code or driving rules for automated vehicles (AVs), to facilitate deployment;
- Current knowledge related to the interaction of VRUs, AVs, and non-AVs;
- Best practices for municipalities to adopt or encourage AV use;
- Benefits and costs of unintended consequences from the standpoint of a city;
- Data-sharing standards and protocols for vehicle-to-vehicle communication;
- A process for certifying road segments for AV operation;
- Reexamination of regulations on distracted driving;
- Enforcement issues and police interaction with AVs;
- Additional needs for regulations governing AVs;
- Potential cybersecurity issues and countermeasures; and
- FOTs to further advance AV deployment, including the automated city center use case scenario (a topic supported by many of the group's participants).

Breakout Group C

Ginger Goodin and Risto Kulmala

Risto Kulmala summarized the discussion of the use case scenario in Breakout Group C. The group participants identified reducing congestion levels and enhancing the quality of life in urban areas as opportunities associated with the case study. They suggested that early education and outreach to users were important for gaining public acceptance of AVs. Possible barriers identified by some participants included the availability of needed technology and the liability and safety issues associated with the interaction of AVs and non-AVs under Level 3 automation.

The group identified the following four research topics as important:

- Behavioral privileges, the human–machine interface, and response times for Level 3 automation to suit all driver segments;
- Demonstration of the use case scenarios in the European Union and the United States with the incorporation of all four automation levels;
- Potential liability issues that might be encountered with Level 3 automation, including a code of practice, standards, and informed consent; and
- Innovative business models for public–private partnerships to deploy elements of the automated city center use case. One example discussed was integrating automated driving and self-parking with insurance reductions, real estate developments, and businesses.

Other research topics identified by individual participants included

- Development of more accurate sensors and efficient vehicle algorithms adapted to address different urban settings,
- Potential land use impacts,
- Approaches for enhancing multimodal mobility,
- Different communication technologies for linking AVs and VRUs,
- FOTs and demonstration projects coordinating the interaction of all user groups, and
- Testing of routes or city centers reserved for AVs connected to a traffic management cloud.

Breakout Group D

Aria Etemad and Steven E. Shladover

Steven Shladover summarized the discussion of the use case scenario in Breakout Group D. He noted that the discussion included some of the potential benefits of Level 3 versus Level 4 automation and reported that participants seemed to favor moving toward Level 4 automation to realize more benefits and eliminate some of the questions about mix traffic conflicts associated with Level 3 automation. Two of the key opportunities participants identified in the automated city center scenario included traffic flow and safety improvements that would result in reduced traffic congestion. Other opportunities included more efficient land utilization from higher density urban parking and improved driver comfort and convenience. The two barriers suggested by some participants as most important were human factors challenges related to drivers reengaging in driving tasks after automated operation disengages and the technical challenges of addressing the complexity of urban environments.

Shladover listed four research topics identified as important by individual participants:

- Potential human factors issues associated with the Level 3 automation used in the automated city center scenario, especially
  - The roles of the driver,
  - Interaction between the driver and the vehicle, and
  - A system for a safe stop if the driver does not reengage in the driving task when automated operation disengages;
- The legal framework for developing and testing Level 3 automation;
- Certification procedures for vehicles and infrastructure in these types of Level 3 automation scenarios; and
- The socioeconomic impacts associated with the scenario and development of a business case for cities to participate in the automated city center use case.

Breakout Group E

David Agnew and Keir Fitch

David Agnew summarized the discussion of the use case scenario in Breakout Group E. He reported that participants discussed possible trade-offs between Level 3 and Level 4 automation and the potential benefits of Level 3 automation in mixed traffic. The participants identified improving the environment of city centers, improving the driving experience for system users, and enhancing safety as possible benefits associated with the automated city center scenario. The potential barriers they discussed focused on the difficulty of managing the mix of AVs and non-AVs in the Level 3 traffic environment.

Agnew noted that the three research topics identified as important by the group focused on the interaction of AVs and non-AVs with Level 3 automation:

- The capacity of drivers operating in an automated mode to reengage in the driving task and the development of a human–machine interface,
- A safe-stop system in a city environment for drivers who have not reengaged in the driving task, and
- The impact of this scenario on traffic flow and VRUs and the benefits of Level 3 automation.

Other research topics discussed in the breakout group were

- Intelligent transportation systems infrastructure and the traffic control systems needed for this scenario,
- Data needed to identify liability in the case of crashes,
- Use of crowd-sourced data to identify safe drop-off areas,
- Maximization of the use of available big data from traffic management centers and related systems when automated city center applications are being developed, and
- The impact of these applications on urban planning, land use, transport modeling, and the environment.

Breakout Group F

Natasha Merat and Jane Lappin

Jane Lappin summarized the discussion of the use case scenario in Breakout Group F. She reported that the group discussed several opportunities, including

- Relieving drivers of the stress of urban driving and providing time for other activities,
- Improving safety,
- Reducing vehicle and pedestrian interactions,
- Enhancing mobility for the elderly and special population groups,
- Increasing the attractiveness of cities with smart infrastructure and smart vehicle services,
- Increasing mobility and reducing congestion in densely developed neighborhoods,
- Increasing private-sector financing, and
- Encouraging public–private partnerships with the business community and property owners.

Potential barriers discussed in the breakout group focused on the possibility of inducing demand and the creation of the need for additional regulations and policies to address negative impacts.

Lappin reviewed the research topics identified by individual breakout group participants:

- Mixed modal operations involving manual and automated vehicles;
- The concept of balancing short-term parking with other demand management policies and practices and using automation to maximize access;
- Policies to accomplish desired urban, commercial, and societal goals of the automated city center scenario;
- Distribution of costs and benefits among different user groups;
- The impact of the automated city center scenario on overall safety, including the interaction of AVs and VRUs;
- The need to adapt the driver interface to support age and human variables in driver capabilities;
- The best approaches for cities of different sizes and configurations, including a comparison of EU and U.S. approaches;
- The need for new traffic models to adequately address the automated city center scenario and other AV applications; and
- The need for new driver behavior models to adequately address all use cases.

Open Discussion

In the open session, individual symposium participants provided additional comments on the merits, opportunities, barriers, and potential research topics associated with the automated city center use case scenario. Much of the discussion focused on the need to better define Level 3 automation and the potential human factors issues associated with Level 3. Some participants suggested that Level 3 was a transition step, or bridge, between Level 2 and Level 4 automation. It was suggested that rather than being a long-term state, Level 3 represents a short-term transition to Level 4. Other participants indicated that Level 3 is appropriate for some AV applications and cautioned against ignoring Level 3 automation. Still other participants suggested that while the automation levels are necessary from a design and development standpoint, automation should be transparent to users.

The potential benefits to a city that would result from the automated city center use case scenario and other AV applications were discussed. Some participants suggested that the use case would increase the attractiveness of a city as well as create opportunities for private-sector investments. Other participants noted the potential to reinvigorate urban areas. It was further suggested that cities would benefit from using land for more valuable purposes than parking.

USE CASE SCENARIO 3

Urban Chauffeur

Fully Automated Tailored Mobility Service

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Richard Bishop, *Bishop Consulting, Granite, Maryland, USA*
Ginger Goodin, *Texas A&M Transportation Institute, College Station, Texas, USA*
Risto Kulmala, *Finnish Transport Agency, Helsinki, Finland*
Aria Etemad, *Volkswagen AG, Wolfsburg, Germany*
Steven E. Shladover, *University of California, Berkeley, Berkeley, California, USA*
Keir Fitch, *European Commission, Brussels, Belgium*
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Presentation of Use Case Scenario 3, Urban Chauffeur: Fully Automated Tailored Mobility Service

Natasha Merat and David Agnew

Natasha Merat and David Agnew, the planning committee champions for Use Case Scenario 3, described this scenario. They summarized the system concept, the operation, the time frame, and the sectoral perspectives. The full text of the use case is given in Appendix C.

Merat reviewed Table 8 and the key characteristics of the urban chauffeur use case. The use case focused on highly automated vehicles (Level 4) that would operate on limited urban routes on which a driver was not required for vehicle control. Users would not own the vehicles. The system concept included vehicles operating on roads shared with other vehicles, pedestrians, and bicyclists, all following a designated route or constrained within a designated area, as well as the use of highly accurate mapping and sensing. Merat noted that it was anticipated that the urban chauffeur service would be operated by the public sector and cited the Google vehicle and the EU CityMobil2 projects as examples of the anticipated approach.

The scenario envisioned vehicles that would provide transportation to local destinations along routes or within designated areas as part of an integrated public transportation system. A user would be able to summon a vehicle on command through a call point or a smartphone. Transporting a single passenger, multiple passengers, and parcels would all be possible. The system would provide mobility to all age groups and users, as users would not need to have driving capabilities.

Agnew suggested that the urban chauffeur use case could be deployed within the next 10 years. The system would provide independent mobility to individuals who did not own a vehicle, those without driving skills, and people with physical limitations for vehicle operation. Users would be able to engage in other tasks during a trip. The system would reduce the need to purchase and maintain a vehicle. He noted that, from a user perspective, potential limitations that might need additional attention included ensuring system availability, the geographic area covered, vehicle speed and wait times, the cost of use, safety, and the overall experience.

Agnew noted that potential benefits for cities included a dramatic reduction in the number of parked vehicles, which would free space for other uses. The reduction in private transport might reduce congestion and emissions while

TABLE 8 Key Characteristics of Use Case 3: Urban Chauffeur

Use Case	Level of Automation (SAE)	Speed (mph)	Dedicated Space	Private or Public	Examples Available Now (Projects)	Interaction with Infrastructure[a]
1. Freeway Platooning	2–3	High (>70)	Possibly both	Both	Sartre, Peloton	3
2. Automated City Center	3–4	Low (10–40)	No	Both	AdaptIVe	4
3. Urban Chauffeur	4	Low (<30)	Both	Public	Google, CityMobil2	5

[a]1 = low, 5 = high.

increasing the use of existing public transportation. Urban areas might become safer and more attractive, especially for vulnerable road users (VRUs). The potential limitations of this use case scenario for cities included ensuring safe communication and interaction between all vehicles and user groups and the emergence of adapted VRU behaviors.

Agnew also discussed potential benefits and limitations of the urban chauffeur scenario for businesses. The potential benefits included opening markets for services and advertising while individuals were in transit and not driving and the possibility that, although the scenario was envisioned as being publically operated, it might also include new urban mobility services offered by the private sector. The potential limitations included reduction in the personal ownership of vehicles, changing business models, and different relationships between public authorities, data service providers, regulators, and businesses.

Breakout Group A

Robert Denaro and Oliver Carsten

Oliver Carsten summarized the discussion of the use case scenario in Breakout Group A. He commented that participants expressed positive reactions to this use case scenario and identified numerous opportunities associated with it. A key opportunity cited by some participants was increasing mobility for all members of society, especially youth, the elderly, individuals with special needs, and individuals with limited incomes. Additional opportunities identified were

- Enhancing public transport services by making them more environmentally friendly and reducing transit travel times and
- Reducing the need for parking, which would allow current parking lots to be used for other purposes and save individuals the cost of parking.

Some participants stated that many of the elements in the use case would be beneficial in all parts of urban and rural areas, not just city centers.

Barriers suggested by the participants included

- The possible perception that the service was for low-income individuals;
- Potential opposition from the parking industry;
- Concerns about personal security, especially for young and older individuals; and
- Reluctance by municipalities to implement automated mobility services because of limited resources and concerns about rapidly evolving technologies making the system outdated.

Carsten noted that the group discussed possible incentives that would encourage cities and communities to become early adopters of automated mobility services.

Carsten reported on six research topics identified by different participants in the breakout group. The two topics that received the strongest support were

- Identification and implementation of an urban test case of a fully automated tailored mobility service in one city or a few cities and
- Development of a concept of operations plan for operating the automated mobility service in shared spaces on city streets.

Other research topics that were suggested were

- Legal issues associated with implementation,
- Paths to deployment involving both private- and public-sector groups, and
- Potential staging approaches.

Carsten noted that participants also suggested that developing best practice guidance based on the results of initial tests and deployment would be beneficial.

Breakout Group B

Roberto Arditi and Richard Bishop

Richard Bishop summarized discussion of the use case scenario in Breakout Group B. Noting that the participants in the group were generally optimistic about the automated mobility services scenario, he listed the following examples of opportunities associated with the scenario that were identified by individual participants: provision of mobility to diverse groups; reduction of the need for vehicle parking, thereby freeing parking facilities for other uses; and provision of more usable time for drivers. Some participants noted that this use case shifted vehicle ownership to vehicle usership, which would represent a major change. Potential barriers discussed by breakout group participants included automated vehicles interacting with nonautomated vehicles, public acceptance, liability in the case of vehicle malfunctions or crashes, and security concerns.

Bishop reviewed 10 of the 24 research topics identified by participants in the breakout group:

- Learning computation functions to enable a more robust operation,
- The potential for unintended interaction with other users,
- Product liability and negligent concerns,
- Links to citywide traffic management systems,
- Implementation of the urban chauffer concept in small-scale demonstrations,
- Implementation of the concept in larger-scale deployments,
- Minimum vehicle-to-vehicle requirements for the service,
- Gap analysis to identify the technology needs to achieve the most robust operation,
- Enhanced traffic modeling techniques to integrate urban chauffeur operations, and
- Identification of critical digital infrastructure needs and vulnerabilities.

Breakout Group C

Ginger Goodin and Risto Kulmala

Ginger Goodin summarized the discussion of the use case scenario in Breakout Group C. Examples of potential benefits suggested by some participants in the group included improving mobility for all groups, enhancing the livability of cities, repurposing parking areas, and improving safety. Some of the possible barriers discussed in the group were public perception and acceptance, technology costs, and security threats.

Goodin indicated that different participants discussed both social acceptance of the urban chauffeur scenario and the readiness of technology to operate the service. Developing, testing, and using standards for ensuring that the automated mobility service vehicles and system were safe for all users was one research topic discussed by participants. Participants suggested that an acceptance testing protocol would include minimum standards and performance requirements. Goodin noted that participants indicated that an EU-U.S.-developed protocol would be beneficial for all public- and private-sector groups.

Another research topic discussed in the group was examining alternative business models and public–private partnerships for developing, testing, and deploying fully automated mobility services, including the supporting infrastructure. Goodin reported that some participants suggested that transitional business models might be appropriate in some situations and that field operation tests (FOTs) could be used to gain experience with alternative public–private models. She noted that participants discussed the benefits of learning from the experiences with the different approaches being used in the CitiMobil2 projects, including policies to support various aspects of the demonstrations.

Goodin reported that other research topics identified by some participants in the breakout group focused on public acceptance of automated mobility services, liability issues, and privacy concerns. Developing and applying a methodology for assessing the impacts, benefits, and costs of automated mobility services and other high-level automation scenarios was also identified as a research topic by some participants.

Breakout Group D

Aria Etemad and Steven E. Shladover

Steven Shladover summarized the discussion of the use case scenario in Breakout Group D. Opportunities with this use case identified by different participants included improving the economic viability of urban areas, reducing the density of private vehicles in urban centers, and providing mobility options for all groups. Participants also suggested that the automated mobility services scenario would allow for the productive use of travel time by individuals and would enhance safety for VRUs. Possible barriers discussed by some breakout group participants were

- Necessary infrastructure modifications and maintenance costs,
- Developing and maintaining vehicle storage areas,
- Interaction of automated vehicles with other road users,
- Public acceptance and trust,
- Cost and equity implications, and
- Unintended consequences.

Shladover reported that the participants discussed several research topics and identified four priority research projects:

- Development of system performance requirements for higher-speed operation,
- FOTs to examine different vehicle and infrastructure needs,
- Examination of behavioral norms to guide automated vehicle development, and
- Alternative business models, including those providing land development opportunities.

Shladover noted that some participants suggested that FOTs could provide a focal point for developing public understanding and acceptance of automated mobility services and road transport automation in general. He suggested that FOTs also provide valuable insight into vehicle and infrastructure needs as well as interaction with other road users.

Breakout Group E

David Agnew and Keir Fitch

Keir Fitch summarized the discussion of the use case scenario for Breakout Group E. Opportunities the participants associated with the scenario included managing congestion, enhancing transit, and improving mobility for diverse user groups. Some participants suggested that the urban chauffer concept could be part of an overall smart cities approach. Possible barriers discussed by participants focused on deployment costs, ensuring safe pickup and drop-off areas, and regulating government vehicle safety features.

Fitch summarized the research topics identified and discussed by individual breakout group participants, as follows:

- The human–machine interface and automated chauffeur for the first and last mile;
- Achievement of a balance between mass transit and personal transit or mobility;
- Identification of where automated vehicles would be most appropriate;
- Design of safe pickup and drop-off areas;
- Investigation and development of different business models for deployment, as well as alternate approaches for urban, suburban, and rural areas;
- Vehicle and infrastructure design criteria to enhance access by individuals with special needs;
- Use of automated mobility services to replace existing paratransit services;
- How to balance escort trips, such as taking children to school, with the positioning of empty vehicles; and
- The business case for automation.

David Agnew noted that some participants also discussed potential safety concerns and technical challenges, as well as possible links between the urban chauffeur scenario, global vehicles, and urban planning.

Breakout Group F

Natasha Merat and Jane Lappin

Natasha Merat summarized the discussion of the use case scenario in Break Group F. She noted that much of the discussion focused on conducting FOTs, although other potential research topics were also identified. Merat reported that different breakout group participants discussed the FOTs under way in the EU. Some participants suggested that FOTs provide a mechanism to obtain real-world experience with different road transport automation scenarios, including automated mobility services. It was noted that the information obtained from the FOTs on user experiences, customer acceptance, technology, business models, legal issues, and other topics was important for accelerating deployment of automated vehicles. Merat reported that some participants noted that there were more FOTs and demonstration projects under way in the European Union than in the United States. Participants suggested that developing a business case for more FOTs in the United States would be beneficial.

Merat noted that many participants suggested that conducting FOTs focused on different automated mobility service applications in different geographical settings in the European Union and in the United States would be beneficial. The FOTs could address different levels, such as fully separated systems, interaction with other vehicles, and interaction with VRUs, as well as different user needs. Participants suggested that sharing the results of these FOTs and developing best case practices between the European Union and the United States would be beneficial.

There was also discussion of the need to include customers in the development of automated mobility services and discussion of technology options and deployment alternatives. Participants suggested that identifying common needs and common barriers associated with the development and use of automated mobility services in the European Union and the United States would be beneficial.

Open Discussion

In the open session, individual symposium participants provided additional comments on the merits, opportunities, barriers, and possible research topics associated with the urban chauffeur use case scenario. Much time was spent discussing the FOTs, demonstrations, and pilot projects that were suggested as research topics in the urban chauffeur use case and the other two use case scenarios. It was suggested that demonstrations involving a few vehicles were much different from demonstrations involving 1,000 vehicles and that large-scale demonstrations involving 10,000 vehicles were even more complex. It was noted that large-scale projects may be moving forward in China.

Some participants suggested the importance of FOTs as learning tools but also stressed that it was important to clearly define the goals and objectives of projects, the evaluation measures being used, and the elements being tested. Participants also discussed the potential differences between FOTs, demonstrations, pilot projects, and deployments. It was suggested that the use of the term "FOT" implied a rigorous pre- and postevaluation process. Other participants said that the exact terms should not stand in the way of moving forward with testing different technologies, services, and delivery methods. It was noted that outlining the basic elements of an evaluation plan that could be shared among all groups would be beneficial.

Different participants discussed the need for both smaller and larger FOTs or demonstrations, noting that lessons can be learned from projects of all sizes. The time it takes to develop political and public support for projects was discussed, and sharing examples of successful approaches for building support was suggested. Other suggestions included review of the demonstrations the military is conducting for transporting injured soldiers on bases and consideration of Google vehicles in demonstrations.

Symposium participants suggested that while FOTs and demonstrations should be pursued, research is also needed on several topics to help advance the urban chauffeur scenario. Expanding on the breakout group summaries, participants suggested research focused on policy and legal issues, human factors, and benefits to cities from the urban chauffeur use case scenario. Other research needs discussed by participants included modeling the traffic impacts of different types of services, examining the interaction with existing public transit services, and assessing approaches to build public acceptance.

Concluding Observations and Discussion

Maxime Flament, *ERTICO-ITS Europe, Brussels, Belgium*

Overarching Themes

Maxime Flament

Maxime Flament offered his perceptions on the overarching themes of the symposium, focusing on five general topic areas: moving ahead with tests and deployments, examining human factors issues, considering potential legal issues, addressing possible measurement impacts, and exploring evolving technology.

Moving Ahead with Tests and Deployments

Flament noted that the potential research topics identified in all the use case scenarios included conducting test beds, field operation tests (FOTs), pilots, and model deployments. He suggested that the focus on moving ahead on multiple projects was reflected in the breakout group summaries for all three use case scenarios and noted that other common research topics included developing best practice guides and case studies for deployment. One topic that was not discussed, Flament observed, was analyzing available data from recent FOTs and pilots. He suggested that much can be learned from examining recent projects and sharing the results and that examining data on truck platooning and truck following might be a productive starting point. He suggested that sharing information would help maximize available resources and ensure that efforts are not duplicated.

Examining Human Factors Issues

Flament noted that different facets related to human factors were discussed in the breakout groups and suggested that developing a system that would be acceptable to users inside and outside vehicles appeared to be a key to addressing human factors issues. He observed that two human factors research topics identified by the breakout groups were (*a*) examining the human–machine interface for Level 3 and (*b*) examining interactions with vulnerable road users and developing a human–machine interface for pedestrians. The topic of safe stops was also noted by different breakout groups. He further suggested that examining available information on behavioral norms on a transatlantic basis would be beneficial.

Considering Potential Legal Issues

Flament noted that several of the potential research topics identified were associated with legal issues and outlined possible general categories for considering the potential legal issues associated with different facets of road transport automation. These categories included developing safe operating rules for different use cases and applications and developing codes of practices for the development of automated vehicles. Flament suggested that lessons learned from the EU Response 3 activities and the code of practice for the development of automated vehicles were very beneficial. He noted that addressing a transatlantic code of practice would have similar benefits, even though there are different liability issues in the European Union and the United States. Developing testing regimes that address verification, validation, and certification would also be beneficial, he said. Other legal topics to be addressed include minimum standards and performance measures, certification of the physical and the digital infrastructure, standards, liabilities, and licensing.

Addressing Possible Measurement Impacts

The fourth general topic area discussed by Flament was assessing the impacts of road transport automation. He suggested that developing a common methodology for conducting evaluations of socioeconomic impact represented a possible parallel trans-America research activity. He further suggested that the recent work by the Volpe Center to develop an impact framework could serve as a starting point for this activity and would be of use in the European Union. Flament noted that the development of business models and evaluation approaches that could be used by cities and public authorities was also suggested in some of the breakout groups.

Exploring Evolving Technology

Flament observed that even with the rapid advancements in technology, there were still challenges associated with technology. Some of the challenges identified in the breakout groups focused on the robustness of sensors and system components as well as the need for vehicle-to-vehicle and infrastructure-to-vehicle requirements, technical requirements, digital map requirements, and identification of the value of data. He suggested that there were potential EU-U.S. collaborative activities in all of these topic areas.

Comments from the Planning Committee and Open Discussion

The members of the symposium planning committee and all symposium participants had the opportunity to provide additional comments on the three use cases and overarching research topics to help advance road transport automation. Some of the comments reflected those provided previously during the breakout group summaries and open discussions on the three use case scenarios. Other comments reflected additional suggestions for research, FOTs and demonstrations, and ongoing communication and coordination.

Several participants noted the importance of many of the potential research topics identified in the breakout group summaries, notably the following:

- Legal and regulatory issues;
- Policy implications;
- Technology readiness concerns;
- Human factors issues;
- Public acceptance;
- Definition of potential public- and private-sector roles and responsibilities;
- Development of business cases for why public agencies and local communities should invest in road automation; participants also noted that businesses will play important roles in developing and offering user services for different markets;
- Human factors issues at Level 3 automation;
- Potential risks;
- Infrastructure needs with different use scenarios;
- A code of practice for the various applications; and
- Identification of roadway certifications.

Individual participants discussed different methods for transatlantic coordination and cooperation. Potential concerns about combining funding were noted. Maintaining separate projects in the European Union and the United States was suggested as a potentially viable approach, with the results to be shared through multiple methods. This approach was suggested for research, FOTs, and demonstration projects. Participants noted that although the political, legal, and organizational frameworks were different in the European Union and the United States, benefits could still be realized by conducting transatlantic projects.

A few participants provided additional comments on FOTs, demonstrations, and pilots. Some suggested that the development and use of test beds might be appropriate. One participant suggested that the approach used in the pharmaceutical industry was a possible model to follow. Many participants suggested that moving forward with FOTs, demonstrations, and pilots of all sizes and sharing the results of these activities would be beneficial.

Closing Session and Final Remarks

Kevin Womack, *U.S. Department of Transportation, Washington, D.C., USA*
Alessandro Damiani, *Directorate-General for Research and Innovation, European Commission, Brussels, Belgium*
Gregory Winfree, *U.S. Department of Transportation, Washington, D.C., USA*
Neil Pedersen, *Transportation Research Board, Washington, D.C., USA*

Closing Comments from the U.S. Department of Transportation

Kevin Womack

Kevin Womack thanked the symposium participants, noting that it was a very invigorating 2 days. He recognized the hard work of the symposium planning committee and all the participants and complimented the discussion group moderators and recorders for facilitating and documenting the productive discussions in the breakout groups. He indicated that the research topics generated in the breakout groups covered many important topics for helping advance road transport automation in the United States and the European Union and affirmed that those research topics would be beneficial for the U.S. Department of Transportation (U.S. DOT).

Womack suggested that more hard work was ahead to translate the research topics into tangible EU-U.S. collaborative projects and challenged the participants to continue to explore transatlantic collaboration opportunities. He pledged his commitment to working with U.S. DOT and European Commission partners to identify transatlantic collaborative projects and studies. He challenged other participants to also follow up within the different stakeholders represented at the symposium. Womack encouraged participants to seek opportunities to collaborate on research, field operation tests (FOTs), pilots, technology development, and policy studies. He further challenged participants to build on the relationships established at the symposium and to continue sharing information and experiences on a regular basis. He stressed that the symposium helped plant the seed for further collaboration and encouraged participants to take advantage of these opportunities.

Closing Comments from the European Commission

Alessandro Damiani

Alessandro Damiani stated that the symposium had been very productive and had exceeded expectations. Numerous benefits were realized from the presentations and the breakout group discussions, he said. Answers were provided to many of the questions posed in the background papers, and some new questions were raised. He suggested that the questions raised enriched the discussion and that defining the right questions was key to identifying appropriate solutions.

Damiani indicated that the symposium was successful in enhancing a common understanding of the problems and possible solutions associated with road transport automation. He noted the success in identifying potential research topics, including those appropriate for transatlantic collaboration and cooperation. Damiani reported that work is under way to define the priorities for the European Commission Transport Research and Innovation Program for 2016–2017. Approximately 50 main priorities would be finalized over the next few weeks. He suggested that the research topics identified in the breakout groups would be of benefit in developing the work program, including projects for transatlantic collaboration. He noted that during the symposium, discussions had occurred with U.S. DOT representatives about approaches for collaborative and coordinated research.

Damiani commented that the discussions at the symposium were very broad and very rich, with topics ranging from technology to human factors to legal and regulatory issues. The discussions identifying the interconnection between these topics were also very beneficial. He highlighted a few topics for consideration for future EU-U.S. collaboration:

- Conducting future FOTs, test beds, large-scale demonstrations, and predeployment projects. Damiani agreed with the previous comments by Maxime Flament that reviewing recent studies and reports to determine the best way to organize a mutually beneficial exchange of information and data would be a logical next step.
- Developing a common methodology to enable an easier exchange of information on future FOTs, pilot tests, and demonstrations.
- Developing standards and certifications. Damiani indicated that it would be important to have similar standards and certifications in Europe and the United States to reduce costs to producers and consumers.

In concluding, Damiani noted that the symposium was very enlightening, useful, and productive. He indicated that there is interest in continuing the partnership and the symposia for another 4 years. Damiani thanked the U.S. DOT and Transportation Research Board (TRB) representatives, the planning committee, the authors of the white paper, and the breakout group moderators and recorders. He also thanked the participants for investing their time and sharing their expertise and ideas to make the symposium an extraordinary and fruitful experience.

Closing Comments from the U.S. Department of Transportation

Gregory Winfree

Gregory Winfree, Assistant Secretary for Research and Innovation, U.S. DOT, thanked Peter Sweatman and the planning committee for organizing the excellent symposium. He also recognized the assistance from TRB and European Commission staff and noted the benefits to the U.S. DOT from the ongoing partnership. Winfree acknowledged the authors of the white papers and thanked the participants for their active involvement in the symposium and for sharing their ideas on future research topics.

Winfree reviewed the topics of previous symposia, which included urban freight and implementing surface transportation research. He observed that in addition to providing opportunities to exchange information, the symposia have provided opportunities to build transatlantic relationships and partnerships. He commented that these relationships allowed for the frank and open discussions of key issues at this symposium and the consideration of automation and future game-changing technologies. Winfree noted that both President Obama and U.S. DOT Secretary Anthony Foxx were very interested in future technology developments to enhance transport operations and safety.

In closing, Winfree challenged the research community to move forward from the symposium and communicate with stakeholders, policy makers, and other groups. He suggested that reaching out to diverse groups to explain the benefits of road transport automation—especially to address any misperceptions of future advancements in technologies—was important. He also suggested that the future changes in this arena would be similar to the leap from the horse and buggy to the automobile.

Closing Comments from the Transportation Research Board

Neil Pedersen

Neil Pedersen added his thanks and congratulations to Peter Sweatman and the symposium planning committee, the authors of the white papers, and the breakout group facilitators and recorders, and to the participants for their active engagement. He stated that the use case scenarios were an excellent approach for providing a realistic focus to the discussions. Pedersen repeated his comments from the opening session that this symposium focused on where hype meets reality and where vision and dreams meet practicality and implementation. He suggested that the use case scenarios set up the discussion with a practical and grounded focus.

Pedersen recognized the TRB staff who assisted with planning and conducting the symposium. He acknowledged Mark Norman, who is leading TRB's new strategic focus on research and outreach on automated vehicles and connected vehicles (AV-CV). Pedersen noted that the information presented at the symposium and the breakout group discussions provided numerous ideas and issues that TRB can pursue. He also recognized the tremendous amount of work Monica Starnes put into ensuring the success of the symposium and the support of Richard Cunard, Michael Miller, and Mai Le. Pedersen also acknowledged the great work of Barbara Siegel, the graphic artist who recorded the highlights from the different sessions, noting her ability to capture key concepts and discussion points.

Pedersen recognized the participation of four TRB Executive Committee members in the symposium: Donald

Osterberg of Schneider National, Inc.; Kirk Steudle of the Michigan Department of Transportation; Abbas Mohaddes of Iteris;[1] and Gregory Winfree of the U.S. Department of Transportation. Pedersen noted that they would be helping to shape TRB's role in this strategic issue and that their participation provided an excellent link with developing TRB's research agenda.

Pedersen noted that the symposium provided an excellent opportunity to learn from experts in the arena of automated road transport. He suggested that just keeping up with the rapid technology developments was a challenge and that the research programs at most public agencies might not be agile enough to respond quickly to these changing needs. Collectively considering approaches to provide more flexibility and quicker responses to key research needs would be beneficial, he suggested.

Pedersen said that it would be a shame if a way was not found to bring this group together again as the topic evolves. As one follow-up activity, Pedersen committed to provide time at the 2016 TRB annual meeting for this group to meet. He noted that possible items of discussion might include activities undertaken since this meeting, the status of research projects and demonstrations, and changes occurring in the marketplace. Pedersen further suggested that the sponsors and partners have a responsibility to ensure continuing learning, communication, cooperation, and collaboration. He noted that TRB is also continuing to define the ever-evolving research agenda.

Pedersen indicated that it is important to identify a method to ensure that joint EU-U.S. activities are adding value and noted that implementing twin or complementary projects was one approach being discussed. He suggested that the numerous projects and activities under way demand attention from an evaluation standpoint and, further, that common evaluation methodologies, common performance metrics, and common approaches to examining issues were needed for twin research projects. He said that identifying this evaluation methodology would be beneficial. Pedersen noted that jointly funded research projects are very difficult because of differences in policies and procedures in the European Union and the United States. Thus, twin projects and parallel efforts appear to be the best approach.

Pedersen stated that finding ways to come together and share experiences and lessons learned is important and that more than just reading reports is needed. Dialog, such as that which took place at this symposium, is necessary. Pedersen noted that there is both a strong private-sector role and a strong public-sector role in advancing AV-CV research and deployment and indicated that it is important to recognize and respect the private-sector role. He further elaborated that the public sector should help the private sector flourish, advance, and use the power of the marketplace. At the same time, AV-CV is a sociotechnical issue that requires the public sector to recognize its own roles and responsibilities and to define research needed to support these responsibilities.

In closing, Pedersen thanked all the participants again for their active engagement throughout the symposium. He stressed TRB's ongoing commitment to supporting the EU-U.S. partnership and advancing research on road transport automation.

[1] Abbas Mohaddes is now chief executive officer of the Mohaddes Group.

Potential Portfolio for EU-U.S. Research on Road Transport Automation

Katherine F. Turnbull, *Texas A&M Transportation Institute, College Station, Texas, USA, Rapporteur*

Katherine Turnbull served as the rapporteur for the symposium. In addition to summarizing the presentations by the breakout group reporters, she had the opportunity to review the list of opportunities, barriers, and potential research topics identified in each breakout group. In the discussion of the three use case scenarios, 245 research topics were identified in 18 breakout groups. Although these research topics ranged from a few words to a few sentences, the opportunities and barriers identified by individual participants helped establish the context for the research areas. Many crosscutting research topics emerged from the discussions.

The rapporteur expanded on the overarching themes provided by Maxime Flament and developed a potential portfolio for EU-U.S. research on road transport automation. The potential research topics are grouped by the following subject areas: public policy and legal issues, automated technologies, design and operations, human factors and public acceptance, field operations tests (FOTs) and demonstrations, and information sharing and ongoing coordination. These research topics may be considered by the U.S. Department of Transportation, the European Commission, the National Cooperative Highway Research Program, and other groups.

Public Policy and Legal Issues

Numerous public policy research topics were discussed during the symposium. These topics addressed legal and regulatory changes that may be needed for widespread use of automated transport services, liability concerns in the event of crashes, and other policy implications, as follows:

- Legal aspects of safety concerns with automated vehicles (AVs), including liability, risk assessment, and risk assignment;
- Potential equity concerns and related policy implications associated with different use case scenarios;
- Policy and regulatory changes relating to traffic laws and vehicle operations needed for deployment of different use cases;
- Possible changes in commercial driver hours of service regulations for drivers of following vehicles in truck platoons; and
- Possible impacts on land use, housing, mobility, development patterns, and the environment from different use case scenarios, including unintended consequences.

Automated Technologies

- Testing regimes that address the verification, validation, and certification of technology performance;
- Testing regimes for the operation of the different use case scenarios;
- Robustness of sensors, digital maps, and other needed technologies;
- Readiness of other technologies needed for different use case scenarios;

- Technical requirements for different technologies, AV applications, and supporting components such as digital maps; and
- Cybersecurity issues related to the different use case scenarios and approaches to mitigate potential concerns.

Design and Operations

- Possible roadway design issues in relation to different AV applications, including entry and exit ramps to accommodate platooning vehicles, self-parking vehicles, and safe pickup and drop-off zones for automated chauffeur services;
- Guidelines for the interaction and integration of transportation management systems, intelligent transportation systems, and AVs (This research would examine the link between existing transportation management systems or intelligent transportation systems projects and future AV use case scenarios. Topics to be examined include data sharing, data integration, and maximizing system operations.);
- Code of practice for the operation of different use case scenarios;
- Guidelines for road design and infrastructure needs for different types of use case scenarios, including the potential of certifying road segments for AVs;
- Approaches to ensure safe stops of vehicles in all types of use cases [Examining safe stops of platooning vehicles (truck-only platoons or platoons involving private passenger vehicles) was one of the early research topics identified by participants, but accommodating safe stops for all use cases was noted as important.];
- Concept of operations plans for platooning vehicles, including joining and leaving a platoon, operating a platoon, and other elements;
- Benefits from truck platooning for suppliers, shippers, and other road users;
- Interaction of AVs and vulnerable road users in different use case scenarios; and
- AV traffic flow and analysis models for different use case scenarios.

Human Factors and Public Acceptance

- Public acceptance of different technologies and automated transport services (research could include reviewing the lessons learned from public acceptance technologies);
- Human factors issues regarding in-vehicle technologies, including factors influencing driver overload and driver distractions;
- Human factors issues associated with Level 3 automation, especially reengaging in the driving task after being in an automated mode; and
- Human–machine interface for Level 4 automation and for pedestrians and other vulnerable road users.

FOTs and Demonstrations

There was strong support from symposium participants for FOTs, demonstrations, pilots, and model deployments. The following research topics were identified by participants to support these ongoing efforts:

- Examination of methods to gain support from cities and communities for FOTs and demonstrations [Possible research could include developing business models outlining the benefits to communities, providing incentives for early adoption of technologies and services, and linking communities and businesses in strategic partnerships (e.g., adopt a community or neighborhood).];
- Development of an overarching guide for evaluating FOTs, demonstrations, pilots, and model deployments (The guide would address the key elements of unbiased evaluations, but it would be scalable to match the objectives, scope, and available resources of different projects. Development of the evaluation guide would draw on guides developed for evaluating other transportation projects.);
- Analysis of available data from current FOTs and demonstrations and sharing of lessons learned (one suggestion was to focus on current experiences with truck platooning and urban transport tests);
- Documentation of the results of FOTs and demonstrations and sharing of information on all aspects, including the technologies utilized, the implementation methods, any policy or regulatory changes, user acceptance, economic and demographic impacts, operations, and overall use;
- Possible innovative business models for testing and deploying different use case scenarios, including public–public and public–private partnerships;
- Paths to deployment, including phased or transitional approaches; and
- FOTs and demonstrations of urban freight AV applications as well as tests of other use cases in urban and rural settings.

Information Sharing and Ongoing Coordination

Several opportunities for ongoing transatlantic information sharing, coordination, and collaboration were suggested by participants during the symposium:

- Present summaries of the symposium by symposium participants and agency staff at conferences and other appropriate venues, such as the annual Automated Vehicles Symposium organized by the Transportation Research Board (TRB) and the Association for Unmanned Vehicle Systems International.
- Encourage participation in the University Transportation Centers Spotlight Conference: Connected and Automated Vehicles, sponsored by TRB and the U.S. Department of Transportation and to be held November 4 and 5, 2015, in Washington, D.C. Hold a meeting of symposium participants as part of the conference.
- Convene symposium participants at the 2016 TRB annual meeting in an information-sharing meeting.
- Develop a general session on the key topics addressed at the symposium for the 2016 TRB annual meeting and promote sessions at future annual meetings and specialty conferences and workshops.

APPENDIX A: COMMISSIONED WHITE PAPER 1

Road Transport Automation as a Public–Private Enterprise

Steven E. Shladover, *University of California, Berkeley, USA*
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The aim of this white paper is to set the scene for discussions at the EU-U.S. symposium on automated vehicles on April 14–15, 2015, in Washington, D.C. The symposium will discuss the most critical issues that need to be resolved in the coming years in road transport automation and will identify areas in which collaborative research can address these issues.

Road transport, as our primary means of transport, facilitates our mobility and lifestyle while also causing major impacts in urban areas and our daily life via air pollution, road crashes, and traffic congestion. Experience shows that we cannot solve the issue simply by building new road infrastructure or extending the existing infrastructure. Intelligent transportation systems (ITS) have proven to be effective tools for improving mobility for people and goods. Successful implementation of such technology requires effective integration with policy.

The domain of automated road transport technology encompasses passenger cars, public transport vehicles, and urban and interurban freight transport. The field of development and deployment of vehicle automation is quite active, with current developments aiming to provide driver support in the form of conditional and partial automation. Although drivers' attention and intervention are currently required, in the long run, the aim of development is toward fully automated vehicles, which hold the potential to enable us to redesign the transport system, our cities, and the way we live.

This paper addresses road transport automation as a public–private enterprise first by introducing the diversity of the different automation concepts, that is, the different goals set for automation, the relative roles of driver and automation systems of different levels of automation, and the complexity of the various operating environments. Next, the state of the art and state of the market are elaborated, including infrastructure support considerations; that section is followed by a discussion of the organizational framework for automation.

As background for the symposium discussions, this paper reviews the maturity of technology with regard to wireless communications, localization, human factors, fault handling, cybersecurity, environmental perception, software safety, ethical considerations in computer control, and research opportunities. An assessment of nontechnological issues covers public policy, legal issues, vehicle certification and licensing, public acceptance, insurance, and benefits and impacts. Business models and the roles of the public as well as private sector are discussed. Private vehicles and public road infrastructure, types and levels of infrastructure support, roadway infrastructure deployment, and business models for financing infrastructure improvements are addressed. The paper concludes with a discussion of key research and policy issues that could be fruitful topics for EU-U.S. cooperative activities.

1 Diversity of Road Transport Automation Concepts of Operation

When considering road transport automation topics, we need to begin with explicit recognition of the great diversity of automation concepts of operation. This diversity of concepts is often an impediment to understanding because unless one precisely articulates the concept under consideration, it is likely that another person will be envisioning a different concept. This diversity also limits the validity of any broad generalizations about automation; something that is true about one form of automation may be completely inapplicable to another.

For the purpose of framing the discussion here, it is useful to think about road transport automation systems in three dimensions: (*a*) the types of goals the system is designed to serve, (*b*) the relative roles of the driver and system in vehicle operation, and (*c*) the complexity of the operating environment.

1.1 System Goals

Road transport automation systems are not ends in themselves but are means of satisfying needs to improve transportation operations or drivers' individual comfort and convenience. Specific systems will be designed to achieve different goals, and those different goals are likely to point toward very different designs. These goals could include combinations of

1. Enhancing driving comfort and convenience,
2. Improving quality of life by freeing up time heretofore consumed by driving,
3. Reducing vehicle user costs,
4. Improving vehicle user safety or broader traffic safety,
5. Reducing user travel time,
6. Enhancing and broadening mobility options and thus giving users more flexibility,
7. Reducing traffic congestion in general,
8. Reducing energy use and pollutant emissions,
9. Making more efficient use of existing road infrastructure, and
10. Reducing the cost of future infrastructure and equipment.

If the priority concern is enhancing the driving comfort and convenience of individual drivers without regard to the broader traffic system, autonomous, sensor-based systems could serve the purpose, without the need to communicate or cooperate with other vehicles or the infrastructure. However, if it is more important to address the societal goals of reducing traffic congestion, energy use, and pollutant emissions, it will be necessary to rely on cooperative systems based on vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and infrastructure to vehicle (I2V) communication of time-critical, real-time operational data. Progress toward these goals will also be enhanced through use of non-time-critical data. If safety is the dominant goal, it will be beneficial to combine the vigilance of the driver with the vigilance of the automation system so that each can handle situations in which the other is not effective, rather than discard the driver's vigilance (at least until the automation technology can be verified to be safer without any driver involvement than with driver involvement).

1.2 Relative Roles of Driver and Automation System

The most critical distinctions between automated driving systems revolve around the relative roles of the driver and the automation system, generally described in terms of the level of automation. Some human factors authorities discourage classification by level of automation because they prefer to think of concepts in which the human and the automation system interact organically, with the boundaries of responsibility shifting dynamically on the basis of the driving environment and the capabilities of the driver. While this may turn out to be true in terms of specific automated driving products, classification by level of automation remains a useful simplification that can help people develop a common understanding of what functions the automation system is required to be able to perform.

Several classification schemes have been defined to distinguish between these levels of automation, beginning with the Bundesanstalt für Strassenwesen, or Federal Highway Research Institute, in Germany and continuing with the National Highway Traffic Safety Administration and the Society of Automotive Engineers (SAE) in the United States. The six-level SAE classification, which is described at length in the SAE Information Report "Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems" (SAE J3016) and which has the most comprehensive and precise descriptions, is discussed here.

1.2.1 Level 0

Level 0 systems have no automated driving functions, but they may be equipped with warning systems that alert the driver to hazards in the driving environment so that the driver can respond earlier and more effectively to those hazards. Level 0 systems can improve safety by adding the vigilance of sensor and threat detection systems to the driver's vigilance.

1.2.2 Levels 1 and 2

Level 1 driver assistance systems may provide automatic speed control or automatic steering of the vehicle while the driver continues to perform the other control function. These systems are already on the market on a variety of vehicles, although they represent a small fraction of the number of vehicles sold. Level 2 partial automation systems have recently been introduced on high-end vehicles and will be introduced on premium vehicles from more manufacturers within the next few years. Both Level 1 and 2 systems provide driving comfort and convenience but require that the driver continuously monitor the driving environment for hazards and be prepared to resume control immediately when the system encounters situations it cannot handle.

1.2.3 Level 3

Level 3 systems—conditional automation—provide higher levels of driver comfort and convenience by allowing the driver to temporarily turn attention away from driving to engage in other activities; however, these systems still require the driver to be available to retake control within a few seconds' notice when the system reaches the limits of its capabilities.

1.2.4 Level 4

Level 4 systems—high automation—include a diverse collection of capabilities that need to be considered individually. These systems can replace drivers completely (i.e., no driver intervention is required). Level 4 systems would operate only under specific limited conditions, which can vary widely from system to system:

- Automated valet parking systems. These systems will park cars in parking lots or garages after the driver has exited the vehicle, making it possible to squeeze vehicles into smaller parking spaces in areas where land is expensive.
- Automated buses. Automated buses on special transitways will be developed as cost-effective alternatives to light-rail transit on high-volume urban routes. The automation technology will provide a rail-like quality of service and the ability to fit within a narrow right of way through accurate steering control, but at a much lower cost than a rail system.
- Automated trucks. Automated trucks on dedicated truck lanes are another high-value niche application of automation that should be possible within the decade by restricting access to those lanes to trucks.
- Automated low-speed shuttles. Such shuttles in campuses or pedestrian zones have been the focus of much attention in Europe through the CityMobil2 project, and several small companies have been developing vehicles for this type of application. Google also recently shifted its attention to this area with the 2014 announcement of its pod car. The European work has depended on certification of the infrastructure in which the vehicle travels, with special design features to limit interactions with other road users and to ensure clear fields of regard for the vehicle sensors that need to detect hazards.
- Automated passenger cars. Automated passenger cars that will operate on limited-access highways (freeways) without the need for driver intervention are likely to be the most broadly applicable Level 4 automation system. Initially (in the 2020 to 2025 time frame), these automation systems will probably only be usable under certain traffic conditions, such as low-speed traffic jams or high-speed operations in light traffic, or in lanes that are restricted to vehicles that are equipped for automation or V2V communication capabilities, analogous to the automated highway system concepts that were developed by the National Automated Highway Systems Consortium in the 1990s.[1]

1.2.5 Level 5

Level 5—full automation—will enable a vehicle to drive itself anywhere and under any condition in which a normal human driver would be able to drive. This concept is the one that captures the public imagination because it allows for full electronic chauffeur service, including

- Electronic taxi service for people who are not able to drive (too old, too young, physically impaired);
- Shared vehicle fleet repositioning, which enables shared vehicle concepts to be economically efficient; and
- Driverless urban goods pickup and delivery.

1.2.6 Discussion of Automation Systems

The Level 4 and Level 5 applications are the ones that could have revolutionary impacts on travel behavior and urban form by eliminating the disutility of travel time, decoupling parking locations from travelers' origins and destinations, facilitating vehicle sharing as well as ridesharing, and breaking down the boundaries between public and private transportation. At Level 4, these impacts are likely to be localized to the zones that are capable of supporting the highest automation capabilities, but at Level 5 they could apply throughout urban regions and even nationally. However, the technological problems that need to be solved before these scenarios can become reality are extremely daunting and will require substantial time and resources. Ultimately, the realization of the highest levels of automation will link strongly

[1] Rillings, J. H. Automated Highways. *Scientific American,* Vol. 277, No. 4, 1997, pp. 80–85.

to the levels of investment in foundational research and system development.

It is possible that the user may experience several levels of automation on a single trip. At some point in the future, it can be envisioned that a user leaving his or her home on surface streets would engage Level 2 automation and upon entering the freeway switch to Level 3. As a further example, depending on the capability of the system, the vehicle may require driver supervision of a lane change (Level 2) before resuming Level 3 operation once it is settled in the new lane. This scenario is hypothetical but serves to illustrate the variations that may appear.

One simple means of understanding the opposing approaches to initiating the deployment of automation was defined by Bryant Walker Smith of the University of South Carolina.[2]

- Everything Somewhere (Google): Very high functionality (Level 4) in a constrained geographical area due to the need to constantly update mapping and limit the interactions with potentially hazardous (higher speed) traffic. Also, given the high functionality, it is likely that the fleet would need frequent servicing and testing to ensure safe operation is maintained; this is also facilitated by geographic constraints.
- Something Everywhere (automotive OEMs [original equipment manufacturers]): This is the classic incremental approach, in which systems are brought to market that are capable of operating on any road (of a certain type, at least) regardless of geographic area.

Another approach espoused by some OEMs could be termed a "something eventually everywhere" scenario. This approach entails sections of roadway being individually approved for automated operation by the OEM or public authorities, or both, on the basis of the availability of map information and potentially by modifications to the supporting infrastructure as required by the public safety agencies or the developers of the automation system. This process may entail the vehicle traveling the route first to collect map information to support the onboard system. (In discussions with industry, Volvo and Ford have voiced support for this approach, although it could be a challenge at the point of sale to explain the system to the customer and for the customer to understand and accept that the higher vehicle automation capabilities are only available in some specific locations.)

[2] Smith, B. W. Strategies to Encourage Vehicle Automation That Have Little to Do with Vehicle Automation. Presented at symposium Autonomous Vehicles: The Legal and Policy Road Ahead, University of Minnesota, Minneapolis, October 31, 2014.

1.3 Complexity of Operating Environment

Road transport automation systems have been proposed for use in a wide variety of operating environments encompassing great differences in complexity. This complexity has a strong influence on the technological challenges the system designers must overcome and is therefore determinative about the timing for market introduction. We need to begin with the recognition that fully automated elevators have been in operation for many decades and automated people mover (APM) systems have been operating on their own dedicated guideways for several decades, carrying millions of passengers through airport terminals and in urban metro systems every day. This is feasible because the operating environments of these systems have been drastically simplified and tailored to their needs to physically exclude hazards and unpredicted occurrences. Dedicated busways or dedicated truck lanes are examples of simplified environments that are more complicated than APM guideways but still a far cry from mixed-use, general-purpose lanes, particularly because they exclude light-duty vehicles, pedestrians, and bicyclists.

Limited-access highways are much less protected than APM guideways, but they are much simpler than urban streets. Product development by the automakers is currently focused on this environment. Physically separated lanes within such facilities (high-occupancy vehicle or managed lanes) are more protected, which makes them promising candidates for introduction of higher-level automated driving systems for private light-duty passenger vehicles. (However, the interactions between infrastructure operator decisions about the establishment of such lanes and automaker decisions about developing products specifically for this operational environment are likely to be complicated in the manner of the chicken-and-egg problem.)

The urban street environment is the most challenging one for automated driving, considering the need to share the street with all other road users, who may appear on very short notice and approach from virtually any direction. Some of these challenges are already being addressed to some degree. The technological foundation is being built with crash warning and mitigation systems that are able to detect some of the threats from vehicles, pedestrians, and bicyclists in urban areas. However, moving to full automation brings substantially higher performance requirements because of the unavailability of a driver to provide the safety backup.

Intermediate complexity can be found in special zones within urban areas, such as shopping malls, pedestrian zones, or campuses of educational institutions, hospitals, or industrial parks. In these environments, different categories of traffic can be separated from each other and rights-of-way can be provided for automated vehicles that minimize their interactions with other road user groups or restrict these interactions and the speed of the automated vehicle to accommodate the technical limitations of the automated vehicle's sensors. Specialized system providers are likely to launch services in such environments; for the mass-production vehicle industry, a high availability of such protected environments would be required to spur product introduction.

Traffic conditions are not the only measure of the environmental complexity with which automated driving systems must contend. Adverse weather and lighting conditions can also make it much more difficult for sensor systems to detect road markings, signs, traffic signals and general hazards. A system that is capable of operating only in benign weather conditions or only in daylight may be viable for introduction as an automotive option but would not necessarily be a significant contribution toward improving the transportation system.

The complexity of the operating environment has a strong influence on the level of external support (V2V or I2V communication of data, or both) that an automated vehicle will need to ensure safe operations. As the environment becomes more complex, the need grows for supplementary data communicated to vehicles about hazards that are not within their immediate line of sight or that can be difficult to perceive (e.g., the state of a traffic signal controller, the acceleration of a vehicle several positions away, or a fault condition in a neighboring vehicle). System developers, motivated by functional safety, need to seek combinations of solutions that have complementary strengths, such as onboard sensing systems that can detect the status of most traffic signals that they approach (subject to lighting conditions and occlusion by obstacles) and I2V communication systems that can provide authoritative information on signal status, but only at the signals that are equipped with the I2V capability.

Roadway operating environments can differ significantly between Europe and the United States, and these differences can lead to the need for somewhat different vehicle automation capabilities. The standards for signage and pavement markings in Europe and the United States are different, as is the level of compliance with applicable standards. Traffic signal systems follow different control strategies, and some of the basic rules of the road are also different (e.g., no passing on the right in Europe, right turns permitted on red signals in most of the United States, strict priority to the right in France).

Europe has also taken the lead in recent years on testing vehicle automation concepts that depend on suitable interactions with infrastructure. The CityMobil2 project is demonstrating the operation of small, low-speed Level 4 automated vehicles on well-defined routes that have been certified to be safe on the basis of modifications to the infrastructure along those routes.[3] These modifications ensure that any obstacles that can intrude into the path of the vehicle will be detectable by the limited-capability sensor suite on the vehicle early enough to allow the vehicle to stop without damaging the obstacle or the vehicle. Similarly, the Drive Me project in Gothenburg, Sweden, will be testing passenger cars with Level 3 automation available in 2017, but only on a specific roadway route that is being equipped with a variety of infrastructure modifications, including safe harbors along the shoulder for automatic parking of impaired vehicles (in cases in which the driver does not respond to a takeover request).[4]

1.4 Summary of Diversity of Concepts

This brief discussion has illustrated the breadth of the topic of road transport automation and the concomitant need to specify which concept of operations is under consideration in any discussion about technological or institutional challenges. The answer that applies for a concept at one end of the complexity scale is likely to be inapplicable for a concept at the other end of the scale.

2 State of the Art and State of the Market

2.1 State of the Art: Prototype Systems

This section provides a sense of the state of the art in the commercial development of automated driving systems. There is also extensive activity in academia and research institutes, but these institutions are not covered here.

2.1.1 Highway Operation

In recent years, many automakers have demonstrated high-functioning prototypes capable of automated longitudinal and lateral control (within conditions of their public demonstrations on test tracks and highways). Recent examples come from Toyota and Honda, who both demonstrated high-functioning prototype automated driving vehicles at the 2014 ITS World Congress, and from Audi, whose automated vehicle was driven on public roadways from Silicon Valley, California, to Las Vegas, Nevada, for the 2015 Consumer Electronics Show (CES). On

[3] For more information on CityMobil2, visit http://www.citymobil2.eu.
[4] Volvo Car Group Initiates Unique Swedish Pilot with Self-Driving Cars on Public Roads. Press release. Volvo Car Group, Dec. 2, 2013. https://www.media.volvocars.com/global/en-gb/media/press releases/136182/volvo-car-group-initiates-world-unique-swedish -pilot-project-with-self-driving-cars-on-public-roads.

freeways in mixed traffic, these vehicles were capable of automated freeway cruising, lane changes, merging, and exiting and can be viewed as Level 2 systems.

During CES 2015, Honda demonstrated a lane-level hazard information function in which an automated vehicle, seeing a lane blockage or hazard ahead, takes a photo of the hazard before performing an automated lane change. This information is then provided to upstream vehicles so that these vehicles can perform the lane change with more advance notice.

Also at CES 2015, Toyota demonstrated its Predictive and Interactive Human Machine Interface, which provides advance information to the driver about upcoming settings in which system support is likely to be reduced. This information is predicted on the basis of upcoming road geometry and historical sensor performance for the lane in which the vehicle is traveling. Toyota's approach also employs driver monitoring in the form of detection of the direction of the driver's gaze and the driver's hands on the steering wheel to try to ensure the driver's proper monitoring of the traffic environment for Level 2 automation.

Audi's demonstration for CES was notable in that this automated vehicle was driven by several journalists during the 550-mile journey, thereby showing Audi's high level of confidence in the system for intercity freeway driving.

2.1.2 *Street Operation*

In 2013, Mercedes demonstrated the ability of a prototype automated vehicle to drive a 104-kilometer route in Germany that traversed three major cities and 23 small towns. The roadways and streets on the route included a typical range of road elements, including traffic signals and roundabouts. Digital maps were used as a reference to support localization and maneuver planning. Similar work has been presented by other automotive OEMs.

The activities of Tier 1 suppliers are an important indicator of the state of the art. Key technological elements include onboard sensors (radar, stereo or mono cameras, lidar) and image-processing systems capable of detecting traffic signal status relevant to the host vehicle's lane. Dynamic maps play an important role and are maintained through car data sharing. On the human–machine interface (HMI) side, the monitoring of driver state is an active topic, as is implementation of the HMI to build user trust.

2.1.3 *Level 4 Automated Chauffeuring*

At this point, Daimler is the only auto manufacturer discussing the convergence of car sharing and automated vehicles as a potential future product that seeks to emulate taxi service with no taxi driver. This is a natural convergence, as Daimler and other automakers have launched car-sharing services. According to Daimler, its approach would bring a vehicle where it is needed to pick up a passenger and drive away on its own when the passenger has disembarked. The vehicle would park itself automatically as needed, as well.

The major player in this space, however, is Google. Its initial work focused strongly on highway driving, but now the focus is on city street automated chauffeuring that operates at low speeds (up to 25 miles per hour). Rather than pursue the incremental approach of the vehicle industry, Google seeks to transform mobility, in particular to serve the needs of those who cannot drive (individuals with visual impairments and the elderly). Vehicles with Level 4 capability would drop off passengers and then continue empty to pick up the next passenger within the zone in which the system has been designed and verified to operate safely. Google's vehicle concepts do not include typical driver controls—steering, brakes, and throttle.

Google has announced plans to begin testing Level 4 chauffeuring on public roads near its headquarters campus in California in approximately 2015. Deployments would be important symbolically but limited in impact, as Google's systems will operate in confined geographic spaces and the number of vehicles will be small, at least for the foreseeable future.

In demonstrations, Google's vehicles have shown the ability to detect and respond to stop signs that are not on its map, a feature that was introduced to deal with temporary signs used at construction sites. However, in a complex situation, such as an unmapped four-way stop, the vehicle might fall back to slow and very cautious driving to avoid making a mistake. Google says that its vehicles can identify almost all unmapped stop signs and would remain safe if they missed a sign because the vehicles are always looking out for traffic, pedestrians, and other obstacles.

Google vehicles have also been demonstrated to recognize and navigate through construction zones, including lane blockages marked by signs and traffic cones. Additional capabilities include handling railroad crossings appropriately, adjusting lateral position for delivery vehicles parked partially blocking the lane, and detecting bicyclists and reading their hand signals.[5] It is not yet known how reliably the Google vehicles can execute all of these essential behaviors.

5 See http://www.technologyreview.com/news/530276/hidden-obstacles-for-googles-self-driving-cars/ and https://www.youtube.com/watch?v=bDOnn0-4Nq8 (Google video).

Other potential entrants into this domain are Uber (which Google partly owns), Lyft, and Sidecar. In particular, in early 2015, Uber and Carnegie Mellon University announced a strategic partnership to create an Uber Advanced Technologies Center. Press releases stated that the Center will focus on "the development of key long-term technologies that advance Uber's mission of bringing safe, reliable transportation to everyone, everywhere. . . . and to invest in leading edge technologies to enable the safe and efficient movement of people and things at giant scale."[6] The partners noted that research and development will focus primarily on the areas of mapping, vehicle safety, and automation technology.

2.1.4 *Automated Trucks*

Highly automated driving capability (Level 3) for trucks will most likely come in the next decade (Mercedes Trucks has shown prototypes and indicated a 2025 time frame). In February 2015 Scania tested short-headway platooning (Level 1, longitudinal only) of several trucks on Dutch highways. These types of operations are expected to be limited to well-structured roadways for long-haul freight movement.

2.1.5 *Summary*

For all of the above prototypes, successful operation has been achieved in demonstrations and during many miles of testing. How well and how consistently this technology can handle everything that can occur on the road is another matter. Each of the major system developers has its own internal metrics and test protocols, but these data are proprietary and therefore not available.

2.2 State of the Market: Product Development and Introduction

2.2.1 *Automotive Manufacturers and Suppliers*

Active safety systems, which form much of the technology foundation for automated vehicles, are now offered on many car models in the European and North American markets. Sales of automotive radars and cameras are in the millions annually. In 2013, Volvo announced it had sold 1 million autobraking automobiles, with the low-speed City Safety system being standard equipment on all of its cars. Active safety systems are becoming standard equipment in increasingly more models; automated emergency braking in the 2015 Mercedes B Class is one example.

Some automobile manufacturers are advocating a long view. Under the leadership of Executive Chairman Bill Ford, the Ford Motor Company has produced Blueprint for Mobility—a plan that describes the company's vision of transportation in 2025 and beyond as well as the technologies, business models, and partnerships needed to get there. Moving beyond today's crash avoidance and automation systems slated for the near term, Ford sees V2V communications becoming mainstream in the midterm. Included will be some automated driving capabilities, such as vehicle platooning to support denser driving patterns. In the longer term, Ford envisions fully automated driving, including parking. Vehicles will communicate with each other and the world around them and become one element of a fully integrated transportation ecosystem. Ford also expects personal vehicle ownership to evolve as new business models develop. The benefits include improved safety, reduced traffic congestion, and the ability to achieve major environmental improvements.[7]

2.2.2 *Level 2 Highway Use Systems*

Some vehicle models now offer simultaneous adaptive cruise control and lane centering when operating at highway speeds on well-structured highways with limited curvature. The degree of road curvature handled by the automatic steering is intentionally limited to prevent drivers from overreliance; the level of steering assist differs across automakers. This capability is available now from automakers including Mercedes, Infiniti, Hyundai, and Acura, and rollouts are expected from other automakers in the near term.

Traffic jam assist is a system that provides automated highway driving in traffic jams; it disables above a speed threshold in the range of 50 kilometers per hour. Even though the system is capable of automatic steering, the driver is expected to keep his or her hands on the wheel. Some systems automatically detect whether the driver's hands are on the wheel and alert the driver if the hands are off the wheel for a set duration; if the driver does not respond, the feature is disabled. Systems are available now from BMW, Mercedes, and Volkswagen. Availability of the system has been announced for 2016 by Audi, GM, and Nissan.

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[6] Spice, B., K. Walters, and K. Carvell. Uber, Carnegie Mellon Announce Strategic Partnership and Creation of Advanced Technologies Center in Pittsburgh. Carnegie Mellon University News, Feb. 2, 2015. http://www.cmu.edu/news/stories/archives/2015/february/uber-partnership.html

[7] Ford Reveals Automated Fusion Hybrid Research Car as Blueprint for Mobility Gathers Pace. Press release. @FordOnline, Dec. 13, 2013. http://www.at.ford.com/news/cn/Pages/Ford%20Reveals%20Automated%20Fusion%20Hybrid%20Research%20Car%20as%20Blueprint%20for%20Mobility%20Gathers%20Pace.aspx.

Level 2 highway automation is Level 2 capability for highway use across the full speed range and a full range of normal highway curvatures. Because this is an eyes-on system, some systems will actively monitor the driver's attention or gaze and warn if the driver does not have eyes on the road. Some systems will simply drive the vehicle in lane; others will also do lane changes as needed. These systems are expected to incorporate traffic jam assist as well. Announcements have been made for availability in 2016 from Audi and GM, 2018 from Nissan, and 2020 from BMW. Toyota has said such a system will be available "middecade."

Aftermarket systems present a unique case. At least one Silicon Valley company, Cruise Automation, has announced that its Cruise RP-1 system can be retrofitted into an existing vehicle (Audi vehicles initially) and provide Level 2 automated highway driving during daylight hours.[8] The company fits a sensor package to the roof of the vehicle and retrofits actuators to the existing pedals and steering wheel. Cruise Automation maintains that the first systems will be delivered in 2015.

2.2.3 *Level 3 Highway Use Systems*

Volvo Cars describes its vehicles being prepared for the Drive Me field test as Level 3. Because members of the public will operate the vehicles, Volvo views this as a production run, albeit very limited in quantity.

2.2.4 *Automation on the Streets*

The complex and varied situations encountered in street driving places this capability much later in the time line; however many automakers are working actively to master this environment as well. Only Nissan has made a specific announcement regarding street operation, stating that vehicles with intersection autonomy capability will be offered by 2020; however, the capabilities to be provided by that function have not been specified.[9]

2.2.5 *Automated Valet Parking*

Valet parking is an interesting application that can be expected to arrive near-term because it is low speed and operates off the public road. The idea is that the driver steps out of the car at the entrance to a parking facility and uses his or her smartphone to instruct the car to park (manufacturer concepts vary with regard to driver responsibilities for monitoring the vehicle's actions). The vehicle drives away empty and finds a space, returning to the entrance when called by the driver. Nissan has announced this feature will be available in 2016; several other automakers have demonstrated prototypes.

2.2.6 *Automated Driving in Trucking*

With V2V communications, two or more trucks can electronically couple such that any braking by the lead truck can be instantaneously initiated by following trucks. This capability enables intervehicle spacing to be greatly reduced, which reduces aerodynamic drag and therefore fuel use.

Initial systems are expected to be Level 1: the system will control only the brakes and throttle, and the driver must steer (automated steering does not improve fuel economy). Truck manufacturers and suppliers are actively developing these systems and addressing safety and performance issues that arise from this mode of operation. Steering is likely to be added in a later generation.

Silicon Valley start-up Peloton is actively seeking to commercialize this function for two-truck pairs. Testing of a two-truck platoon by Peloton has shown 10% fuel reduction in the following truck and 4% fuel reduction in the lead truck (because of reduced turbulence behind it).[10] These are very compelling numbers for the truck industry, and implementation of such systems is expected within 2 to 3 years.

2.2.7 *Addressing the Hype*

Other automakers have made broad statements as to their intentions to offer some level of automated driving capability soon. For instance, Tesla Chief Executive Officer Elon Musk has stated that a "mostly autonomous automobile" will be released in 2015 that will "probably be 90% capable of autopilot."[11] This statement illustrates the hype issue: rolling out automated driving has become highly competitive, and automakers seek to position themselves as leaders for public perception purposes. Their statements may or may not be

[8] Kolody, L. Before Cars Go Totally Driverless, Cruise Wants to Put Them on "Highway Autopilot." *Wall Street Journal*, June 23, 2014. http://blogs.wsj.com/venturecapital/2014/06/23/before-cars-go-totally-driverless-cruise-wants-to-put-them-on-highway-autopilot/.

[9] Carlos Ghosn Outlines Launch Timetable for Autonomous Drive Technologies. Press release. Nissan, July 16, 2014. http://nissannews.com/en-US/nissan/usa/releases/carlos-ghosn-outlines-launch-timetable-for-autonomous-drive-technologies.

[10] M. Roeth. CR England Peloton Technology Platooning Test Nov 2013. Letter report. North American Council for Freight Efficiency, 2013. http://nacfe.org/wp-content/uploads/2013/12/CR-England.pdf.

[11] Elon Musk: Tesla: 90% Autonomous in 2015. Video. CNN Money, Oct. 2, 2014. http://money.cnn.com/video/technology/innovationnation/2014/10/02/elon-musk-tesla-90-autonomous.cnnmoney/.

grounded in the reality of the specific products they plan to roll out (which are likely not yet fully defined because of uncertainties in technical performance and cost) or the timing of the market introduction. Nevertheless, these highly public statements are meaningful as an indication of internal company priorities and levels of investment.

2.2.8 *Infrastructure Support Considerations*

Will infrastructure support be needed to enhance the safety and reliability of automated driving products offered by the automotive OEMs? The answer relates to the nature of the automotive industry. Current systems such as lane departure warning only function if adequate lane markings are present; if that is not the case, the system disables. The customer, when understanding the system properly, realizes that the system is available only when the infrastructure enables it. The automakers are careful to explain the limitations of the system in the owner's manual. Thus, lane departure warning is a system that does not require 100% availability. The same is true of current automated lane-centering systems.

If we extrapolate forward to early forms of automation, the same principles could apply as long as the driver has eyes on the road (Level 2 automation). As the supervisor of vehicle system operation, the driver is responsible for detecting when the system is not providing support and taking control of the vehicle when needed. However, for higher levels of automation, the driver's active attention is not required. The vehicle must therefore have an understanding of when the road situation is adequate for automated driving. If it is not, either the driver must be brought back into the loop or the vehicle must find a safe harbor and stop.

To deploy highly automated driving, the automobile industry must ensure that fundamental system operation is handled under normal driving conditions by onboard systems. This capability includes detection of other vehicles as well as traffic signals and traffic signs; the latter are detected via cameras in current prototypes. Digital infrastructure, which provides up-to-date data on infrastructure elements, appears to be an important factor that vehicle OEMs can control to some degree via contractual relationships with map providers. Public infrastructure elements (from high-quality lane markings to more advanced elements such as V2I-based traffic signal phasing and timing), which increase scene understanding for the vehicle, are going to be important in providing the levels of robustness that customers should expect for systems that do not require constant driver supervision. However, automotive OEMs are aware that they cannot depend on public infrastructure in every instance for many years to come, if ever. If these OEMs cannot ensure a basic level of system operation or a means of alerting the driver to resume control in a safe manner through onboard systems within their own sphere of control (e.g., via sensors and maps, as noted above), then the more advanced levels of automation will not be introduced until they can.

That said, the efforts by vehicle OEMs to work with the public sector to install electric vehicle charging infrastructure could be instructive. If the OEMs were to take a highly activist stance toward installation of public infrastructure and develop partnerships with road operators, progress toward increasingly higher levels of automation could be accelerated. However acceleration will only be feasible if installation of such supporting elements occurs on a reliable time line.

Several possible scenarios can be envisioned as a starting point for stimulating discussion:

- Straightforward private sector alone: Onboard technology plus data flowing to vehicles via private-sector providers provides sufficient performance to proceed to Level 3 and higher.
- Learn-as-you-go private sector alone: OEMs introduce onboard technology that is called Level 2, but in most cases Level 3 operation is possible. The owner's manual has numerous caveats as to the system's capability. Customers are left more or less to discover the system's limitations themselves and make their own choices about keeping eyes on or not. (As a precedent, customers must have fairly sophisticated understanding for some driver assistance systems now on the market.)
- Private industry and the general public goad the public sector into action on infrastructure support: OEMs offer Level 3 systems only on preapproved roads that have sufficient map data and infrastructure support. The public, frustrated with these limitations, clamors for state and local agencies to upgrade their road networks (both physical and digital elements) so as to expand the approved set of roads.
- Public sector provides essential infrastructure support to Level 3 systems: Via the normal processes of ITS deployment and road maintenance, I2V-V2I capability is widespread, lane markings are good, signage is good, and so forth. If the road operators judge automation to be sufficiently beneficial for efficiency of operation or for the reduction of infrastructure cost, they could be motivated to shift their investments to support the automation.

2.3 Organizational Framework

Many types of organizations will be influenced by the advent of road transport automation and will seek to influence its development and deployment. Indeed, road automation has few rivals as a complicated sociotechnical system with the potential to influence the daily lives of the entire population in developed countries. The list of organizations and groups likely to be influenced by developments in road transport automation includes the following:

- Vehicle manufacturers and suppliers. Vehicle manufacturers and suppliers will be developing much of the technology to implement road transport automation and deciding its viability in the commercial marketplace. This group includes not only the automotive manufacturers but also manufacturers of heavy vehicles (truck and bus) and their supply chains.
- Other technology industries. The technological requirements for road transport automation extend well beyond the vehicle industry to encompass the broader information technology and telecommunications industries—which will need to provide much of the required enabling technology—and the roadway infrastructure supply industry.
- Regulators and public authorities. Road transport automation does not fit neatly within the existing regulatory framework for vehicle technology and operations, so considerable attention will have to be devoted to determining how the regulatory frameworks will need to be modified to find an appropriate balance between protecting public safety and encouraging innovation. Automation concepts that depend on roadway infrastructure support or cooperation will also have to be implemented within the fiscal constraints that govern public infrastructure investments.
- Infrastructure and road operators. These operators are generally public, but in some cases may also be private or public–private partnerships. They will need to interact closely with the technology developers and suppliers to ensure that the needed enhancements to their infrastructure are implemented. In the longer term, there may be opportunities for integrated infrastructure–vehicle-operating organizations that can offer automated road transport as a service to travelers on the basis of on higher levels of automation.
- Public transport operators. Public transport operators are potential early adopters of road transport automation technology on the basis of the potential for saving costs, improving service, and building on opportunities to combine their infrastructure and vehicle operation responsibilities. Line-haul transit with high-value vehicles operating on geographically constrained fixed routes and feeder services at low speeds in activity centers are promising targets of opportunity. Automation concepts that depend on roadway infrastructure support or cooperation will also have to be implemented within the fiscal constraints that govern infrastructure investments for public transport operators, but once a transit operator has built the physical infrastructure that it needs (such as a busway), the incremental cost of enhancements to support automation is small.
- Goods movement. Trucking operations could benefit enormously from adoption of automation technology to save money and improve operational efficiency. The early opportunities are in line-haul movements of heavy trucks, but in the long term there could be opportunities for efficient movement of urban goods when the technology becomes available for Level 5 automation. Although low profit margins and the inherent conservatism of this industry are impediments to its early adoption of new technology, applications that provide strong return on investment (such as fuel economy benefits from truck platooning) could be sufficiently compelling to overcome conservative reservations.
- Users–drivers. Drivers of private personal vehicles will be the beneficiaries of improvements in comfort and convenience as well as transportation system improvements (safety, traffic flow speed and smoothness, and energy savings) that result from automation. They will also have to be convinced, however, that their direct benefits will be sufficient to justify the additional costs of equipping their vehicles with automated driving options. The propensity to adopt automation will vary widely across the population, and there will always be a portion of the population opposed to relinquishing driving tasks.
- Vulnerable road users. Pedestrian and bicycling interests have been among the most vocal opponents of automation to date because of concerns about how more highly automated vehicles will interact with them. It will be necessary to provide convincing demonstrations that automated driving systems can detect and respond safely to pedestrians and bicyclists before these systems will be widely accepted for use in urban environments.
- Operators of shared vehicles and fleets. When Level 5 automation becomes available, it is likely to make shared vehicle operations significantly more efficient than they are today by enabling the repositioning of unused vehicles to the locations where they are most needed without the use of human labor. These operators could thereby become one of the primary beneficiaries of automation.
- Insurers. The insurance business model seeks to spread risk sufficiently to make a profit. For the foreseeable future, insurance will continue to play its traditional role in the road transport ecosystem, even as crash avoidance systems proliferate and automation becomes available. Insurance is further discussed in Section 4.5 of this paper.
- Big data service providers. When drivers are able to safely disengage from the driving task because of automation, they will be able to use their time in the car for online activities; as information consumers, they will represent market growth opportunities for online

businesses. The increased connectedness of vehicles will create new data collection opportunities for the information technology industry, but these opportunities are more directly associated with connected vehicles than with automated vehicles.

- Research and academia. Road transport automation has the potential to produce large changes in many aspects of road transport that are not easy to understand. Research on many of these issues will be needed to develop the knowledge required to inform decision makers throughout the transportation world. Opinions differ with regard to the amount of research that will be needed to provide the technological foundations for the higher levels of automation, ranging from requiring significant progress in several technological fields to requiring fundamental breakthroughs in those fields. Research is also needed in nontechnological fields, such as the social sciences, behavioral psychology, law, and economics.
- Legal system. The existing legal environment for road transport is based on the assumption that the driver is in control of the vehicle's movements and is responsible for vehicle safety. As automation shifts some of that control and responsibility to vehicle developers, the legal system will adapt and case law will evolve. This evolution will differ in the United States and Europe, given the differences in their respective legal systems.

Automation has the potential to create new relationships between these different categories of stakeholders because of the changes it can enable with regard to the basic functionality of road vehicles. Relationships between insurance companies, drivers, vehicle owners, and vehicle manufacturers are likely to become more complicated. Similarly, new partnerships could be formed between vehicle developers, infrastructure owner–operators, and vehicle operators to sell transportation services to the public rather than vehicles. The nature of public transportation and goods movement could change significantly and in turn and create new opportunities.

3 Maturity of the Technology

The technology for road transport automation has been advancing for the past six decades in several distinct waves of progress. SAE Level 1 and 2 automation systems have already advanced to market introduction in limited numbers, while development work continues on the issues that need to be resolved to advance to the higher levels of automation. The maturity of the technology will determine which of the specific automation concepts discussed above can become commercially available for general use.

Care is needed in assessing the maturity of the technologies for automation, especially for the higher levels (Levels 3 to 5), at which it cannot be assumed that the driver will be able to intervene when the system has a problem. At these automation levels, the system needs to be fully responsible for ensuring safety, which means that the "ility" measures of effectiveness for the enabling technologies (reliability, availability) become much more important than they were for the lower levels of automation. The probabilities of failure of each safety-critical technology need to be extremely small for the system to meet the minimum acceptability goal of being no less safe than today's driving.

The key enabling technologies are discussed here, in order of increasing difficulty from those that are already relatively mature to those that will require substantially more development effort. These issues are heavily focused on the vehicle side rather than the infrastructure side because this is where the main technological challenges appear to be; the infrastructure technologies that already exist for nonautomated ITS (traffic management systems, traffic detectors, V2I-I2V communication systems and their back-office functionalities) appear to be largely adequate to meet the needs of automated road transport systems.

3.1 Wireless Communications

Wireless communications have already benefited from a great deal of development effort associated with the Connected Vehicle Program in the United States and Cooperative ITS in Europe and within the broader wireless telecommunications industry. Non-safety-critical wireless communications that use cellular radio technologies (3G, 4G LTE, WiMAX) have been developed commercially for a wide range of applications and are already in widespread commercial use. Development is already advancing on future generation enhancements to support the seemingly boundless demand for wireless information transfers, especially for infotainment applications. Message latencies are decreasing such that a wide range of ITS applications can be supported, but they have not reached a level sufficient for safety-of-life applications (nor are they expected to in the future). Some automotive OEMs see commercial wireless technologies being used extensively by automated vehicles to receive quasi-real-time map data, as well as to upload data to refresh the map data.

The time-critical, safety-critical wireless communication technology of 5.9 GHz dedicated short-range communication (DSRC) has been developed with a large public-sector investment, primarily to support cooperative collision warning applications.

The underlying technology, as used for cooperative collision warnings, should be able to support the large majority of the requirements for road transport automation. The issues that still need to be resolved include

- Expanding messages to include information needs specific to automation,
- Verifying that the available spectrum and technical standards will be able to support the wireless traffic demand when a high percentage of vehicles in high-density locations are automated, and
- Verifying that the security systems are indeed sufficiently secure and scalable to a high market penetration.

Other complementary wireless technologies (including infrared line-of-sight communication at short range) should also be researched as alternatives to DSRC. Because it is not possible to ensure that wireless communications will work 100% of the time, research attention also needs to be given to how to make them as fault tolerant as possible, a concept that includes broader concepts of functional redundancy.

As noted above, the vehicle industry will deploy systems with sufficient onboard sensing to allow for a minimum acceptable level of performance; however, that performance will be limited to lower capabilities than in situations when key data are available via communications. This limitation is unavoidable, as a situation in which absolutely all other vehicles will be equipped with V2V is not in the foreseeable future.

3.2 Localization

The most widely used localization approaches involve global navigation satellite systems (GNSS) such as GPS and Galileo, which have become remarkably cheap in recent years. However, these systems' accuracy of localization is not sufficient to be the primary source of information on relative vehicle positioning for automated driving information. More importantly, they are not sufficiently dependable to serve as the primary localization mechanism for safety-of-life applications because of their vulnerability to disruption on the basis of inadequate sky coverage; occlusion of signals by structures, foliage, and large vehicles; and interference, including jamming and hacking of signals. At the very least, these systems need to be augmented with inertial measurement units, or IMU, to provide dead reckoning between GNSS updates and for brief signal interruptions.

An alternate approach to localization that has been attracting interest recently is simultaneous localization and mapping (SLAM).[12] This technique typically uses wide-angle laser scanners to identify targets in the environment surrounding the vehicle and matches those targets to a preexisting detailed database of the environment. That matching can be done effectively when the laser scanner has a clear line of sight to the surrounding environment; this characteristic favors mounting the scanner on top of the vehicle to minimize occlusion of static infrastructure elements by adjacent vehicles. Alternatively, because of styling considerations, future systems may have multiple sensors mounted at the bumper level to seek to provide full coverage. However, the SLAM technique can still be defeated when a vehicle is surrounded by taller vehicles that block the scanner's view of the mapped environment. Creating and maintaining the detailed database of the driving environment requires substantial effort, especially in locations where there is active construction activity or foliage grows rapidly.

Although automated vehicle systems will operate primarily via onboard sensing for tactical driving, several vehicle OEMs stress the importance of up-to-the-minute map information that can provide data on lane closures, work zones, weather, and other dynamic factors. Additionally, for localization, there is active discussion of the concept of "digital horizon data," which would primarily be provided via probe data communications from cars with relevant sensors (radar, lidar, camera) reporting on an exception basis to update the static SLAM data. These data would provide a reference of what the sensors see in the way it is viewed. From these data, road and roadside features would be detected, including curbs, lampposts, trees, and so forth. In this way, the car can localize itself to the road situation in the same way drivers do; this level of accuracy cannot be obtained from satellite positioning. In such an approach, interoperability across map and data providers is essential.

Nokia HERE, one example from the mapmaking industry, is aiming to provide maps at a level of detail to match the capabilities of onboard sensors. Continuous updates would be provided via probe data, particularly for time-variable issues such as lane closures. Nokia HERE's automated driving framework includes

- A high-definition map that provides for precise positioning for lateral and longitudinal control of the vehicle on the road surface,
- The provision of dynamic data to support active planning of vehicle control maneuvers beyond sensor visibility, and

[12] Leonard, J. J., and H. F. Durrant-Whyte. Simultaneous Map Building and Localization for an Autonomous Mobile Robot. *Proc., IEEE/RSJ International Workshop on Intelligent Robots and Systems '91. Vol. 1: Intelligence for Mechanical Systems*, International House Osaka, Osaka, Japan, Nov. 3–5, 1991, pp. 1442–1447.

- The use of vehicle probe data to make automated driving more human-like, so as to increase comfort for vehicle occupants.[13]

In the end, robust localization is likely to require combinations of different technologies so that the limitations of one technology can be compensated for by another. This requirement obviously increases the cost of the deployed system. Research will be needed to identify the most cost-effective way of achieving vehicle positioning with the required accuracy, reliability, and availability.

3.3 Human Factors

The interactions between humans and automated road transport systems will be complicated and require a great deal of research attention. This issue is considerably more than one of enabling technology, but there is an enabling technology dimension that should be addressed here. That dimension is learning (*a*) how to design driver interfaces that will facilitate transitions between human and automated driving and (*b*) how to deter drivers from misusing Level 2 and 3 automation systems by engaging in activities that prevent them from being able to intervene when they need to provide the backup for the automated driving systems.

At the societal level, an alternative to deterring drivers from misuse is to leave this aspect to personal responsibility. Although this is an imperfect solution, it is the approach used for other potentially dangerous behavior, such as speeding. There are some differences, however. Speeding is generally a conscious decision to disregard an explicit rule, whereas a driver who is not attending to the road scene in a Level 2 automated vehicle system is more likely to be disregarding the instructions in the vehicle owner's manual or relying on an incorrect mental model of the system capabilities. More-complex HMI factors that can arise with misuse of automation systems could be associated with difficulties in understanding the limitations of human behavior and of the technological capabilities of the automated vehicle system.

It is not yet clear whether it will be possible to implement a driver–vehicle interface that can successfully manage the rapid (within a few seconds) transition of control to a disengaged driver in a Level 3 system and prevent the driver from tuning out so seriously that he or she is unable to intervene when needed. Consequently, it is not clear if and when systems at Level 3 can be brought to market.

It is also possible that safety risks could result from drivers misunderstanding the overall (or moment-to-moment) limits of the system. This possibility emphasizes the need for intuitive and clearly understandable driver–vehicle interfaces.

There is extensive literature in human factors about the inability of humans to retain vigilance for monitoring-only tasks, and there is already anecdotal evidence (YouTube videos) showing how some drivers will deliberately act to defeat vehicle designers' attempts to force them to remain engaged in the driving task when the lateral and longitudinal control have been turned over to a Level 2 automated driving system.[14,15] Vehicle OEMs are likely to address this issue via carefully worded owner's manuals to reduce the risk of being held liable for driver misuse. However, from a societal standpoint, these behaviors indicate the need for more research to address human factors issues such as

- How can a driver interface best compel a driver to remain vigilant in a Level 2 or 3 automation system without the interface being a nuisance?
- If a driver temporarily disengages from driving to perform other tasks, what is the best way for a driver interface to regain the driver's attention when it is needed?
- How much time is needed for the driver to safely retake control of the vehicle at various levels of automation?
- What are the safety implications when a driver resumes control of the vehicle after an extended period of automated driving, and what extra assistance may that driver need to avoid errors? (And to what degree will the collision avoidance cocoon provide a safety buffer?)

A very important human factors issue arises with the possibility that the driver does not respond to a takeover request because of impairment, inattention, or other factors. Although this may be caused by a human error (or the automation system misleading the human to adopt an incorrect mental model), the response is then left to the vehicle systems to maintain safe operation in some manner regardless of the circumstances. The approach favored by several automakers is to bring the vehicle to a safe stop, ideally by pulling off the road completely. When this is not possible, other alternatives that have been discussed are stopping on a freeway shoulder or even stopping in the lane of travel. The latter is problematic but nevertheless may be safer than continuing vehicle movement when the perception system cannot determine a safe path. The range of possible countermeasures to this situation may be a topic for policy makers to address as well.

Because these issues address general human capabilities and limitations, they should be viable topics for

[13] Rabel, D. Automated Driving Cloud: HD Live Map. Presented at Automotive Tech.AD Berlin 2015, Berlin, German, Feb. 26–27, 2015.

[14] Mercedes S Class Active Lane Assist Hack. https://www.youtube.com/watch?v=Kv9JYqhFV-M.

[15] Infiniti Q50 Active Lane Control—Selfdriving Car. https://www.youtube.com/watch?v=zY_zqEmKV1k.

international cooperation, even though the characteristics of the driver populations and their driving behavior may differ considerably between the United States and the European Union.

3.4 Fault Detection, Identification, and Accommodation

To achieve Level 3, 4, or 5 automation with no less safety than today's manual driving, the automated driving system will have to reach extremely high levels of reliability. Achieving that reliability will require that the system have multiple layers of protection against faults so that it can prevent the vehicle from crashing after a fault (or combination of multiple faults) has been encountered. From a consumer product perspective, automotive OEMs will need to further ensure that any vehicle maneuvers resulting from system faults do not unsettle the driver and erode trust in the system.

The potential faults will be many and varied and may occur individually or in combinations of multiple faults. The faults could be failures of mechanical or electronic components in the subject vehicle or in other vehicles or the infrastructure that are providing information to the subject vehicle, but they could also represent software errors in any of the embedded processors or one of the many external hazards (e.g., obstacles in the vehicle path, environmental obscurants, or cyberattacks).

Although some faults can be anticipated when the automation system is designed, others (especially combinations of faults and external hazards) cannot be anticipated in specific terms. Nevertheless, the system will have to be able to respond safely to nearly all of these faults in order to reach its system safety goals. That ability to respond has to be built into the automation software from the start, following a general sequence of

- Detecting that a fault has occurred (and alerting the driver),
- Identifying the nature of the fault with enough specificity that the system can select a safe response, and
- Accommodating the fault by modifying the behavior of the automation system to isolate the faulty subsystem and commanding the vehicle to switch into a degraded mode of operation that sacrifices normal measures of effectiveness, such as efficiency and ride quality, to ensure that the safety of the subject vehicle's occupants and its neighbors is protected (this could be as simple as bringing the vehicle to a stop promptly or could involve more complicated evasive maneuvers).

Methods of fault detection, identification, and accommodation have been developed and applied in a variety of application domains, but road transport automation is a particularly challenging application because it is safety-of-life critical, it has to be implemented in a consumer product affordable to the mass market, and it has to operate in a highly stochastic environment with diverse hazards that cannot be predicted. All of these factors require major advances in the state of the art of fault detection, identification, and accommodation, from the level of theory to practical implementation. The classical approach to ensuring high reliability of systems involves designing in redundancy, so that if one component fails there is a backup system available to take over. This is an effective but very expensive approach that is widely used in the aerospace industry (e.g., quadruple redundancy of aircraft hydraulic and navigation systems). The price sensitivity of the automotive market makes it difficult to extend this type of brute-force approach to road vehicle automation systems. Nevertheless, the automobile industry is strongly focused on developing systems that implement redundancy through other methods.

The vehicle industry has made strides in this respect for advanced crash avoidance systems; new techniques and methodologies are now under development for automated driving. Current thinking in the vehicle industry is illustrated by a recent presentation on this subject that noted the following points:[16]

- Vehicle OEMs will (and have) set their own internal criteria for system operation prior to releasing products.
- Definition of safety must be done for each functional level. One approach would be to stop the vehicle and await response from the human occupants; another would be to allow for a remote operator to access all controls and drive remotely to maintain safety.
- Emergency handling (situations within approximately the next 10 seconds) must be able to function without driver input.
- Functional decomposition of complex systems is done to try to find all possibly significant situations by permutation.
- Design for high reliability includes redundant, self-monitoring components.
- Standards need to cover all significant potential crash causes, but perhaps not the most unlikely multi-reason crash scenarios.

It is not yet clear whether this type of approach can be implemented with an affordable level of effort in labor and time to reach a safety level that will exceed the safety of today's manually driven traffic, or whether methodological breakthroughs will be needed to get there.

[16] Schöner, H.-P. Challenges and Approaches for Testing of Highly Automated Vehicles. Presented at CESA 3.0, Paris, Dec. 3–4, 2014.

3.5 Cybersecurity

The media have raised public awareness about cybersecurity threats after a series of highly publicized attacks. Such threats are typically one of the first concerns to be raised when the subject of road transport automation is discussed by the media or the general public. Experts in the field have cautioned that cybersecurity should already be a concern for the vehicles that are on the market today and that efforts to address it should not wait for the advent of more highly automated vehicles. Modern road vehicles already have electronically controlled engines, brakes, and steering, and the actuation systems for these functions are on vehicle networks. An attacker who could access that vehicle network could issue commands to those actuators in a current production vehicle to cause unsafe behavior. Vehicles that have wireless connections to the outside world (as many vehicles already do) can potentially be attacked through those wireless connections, but an attacker who can gain physical access to the vehicle has easier ways of executing an attack. Connected vehicles will also have more opportunities to detect an attack and to alert each other about attacks in progress.[17]

With regard to cybersecurity protection, the only substantive difference between today's vehicles and future, more highly automated vehicles is in the ability of the driver to recognize that something is wrong and to intervene to take corrective action. If a driver in a Level 3 to Level 5 automated vehicle is thoroughly disengaged, he or she will not be able to recognize the problem or intervene, whereas a driver of a more conventional vehicle is more likely to recognize anomalous behavior (which may or may not help the driver take corrective action, depending on how severe and complete the attack is). Naïve hackers may perceive automated vehicles to be more attractive targets than conventional vehicles, but sophisticated hackers will recognize that all modern vehicles are similarly vulnerable.

Automakers are actively working to define and implement adequate levels of security against attacks for today's products. More research is needed to provide the highest possible robustness against attacks. The resulting design principles can be expected to be applied and refined for automation.

3.6 Environment Perception

The most visible and readily apparent technological requirement for road transport automation is the ability of the vehicle to perceive its environment accurately and dependably. Extensive resources based on use of a variety of technologies have been devoted to this topic over the decades, and the topic has been a favorite of university researchers in electrical engineering and computer science, who publish many papers in this field every year.

The key challenge in environment perception for automated road transport systems is in ensuring that the subject vehicle can detect and identify all hazards that will adversely affect its safety early enough to take evasive action and, at the same time, avoid false alarms from targets that are not hazardous. The environment perception system typically includes sensors and communication devices that receive input data, signal-processing systems and software to analyze the data from the sensors, and communication devices and threat assessment software to discriminate between the true and false hazards. In current vehicle systems, the sensors are typically video cameras and millimeter wave radar or laser radar (lidar) plus ultrasonic presence detection sensors for very short-range hazards. Each type of sensor has its advantages and disadvantages, and no single sensor represents a silver bullet that will meet all needs. Indeed, it is likely that combinations of sensors with complementary failure modes will be needed to provide robust detection of the most safety-critical environment perception information.

Prototypes of Level 2 automated driving systems have used sensors already on production vehicles (with some modifications) plus additional sensors. The messaging from vehicle OEMs is that a technologically mature set of sensors that will be sufficient for the next generation of automation now exists, but that next generation is still only at Level 2. As upgrades are needed for higher levels of automation that can detect all potential threats with a very high probability of success, the cost of the overall sensor package, and of the system as a whole, will be a pacing factor for introduction of systems with higher functionality.

Environment perception issues pose severe technical challenges for the higher levels of automation for several reasons:

- The probability of a false negative detection (failure to detect a dangerous object or condition early enough to avoid it) must be extremely low in order to achieve system safety no less than today's driving by a human operator. Some hazards are extremely challenging to detect at a range that is long enough to allow a vehicle to respond to avoid the hazard, especially when the hazard has been occluded from view by other vehicles (potholes, rocks, or bricks in the path of the vehicle's tires).
- The probability of a false positive detection (identifying a benign object to be hazardous) must also be extremely low to attain user acceptance. For example, if an automated vehicle brakes hard to avoid a newspaper or paper bag or balloon blowing across its path, the user

[17] Petit, J., and S. E. Shladover. Potential Cyberattacks on Automated Vehicles. *IEEE Transactions on Intelligent Transportation Systems,* Vol. 16, No. 2, 2015, pp. 546–556. http://ieeexplore.ieee.org/search/searchresult.jsp?newsearch=true&queryText=Potential%20Cyberattacks%20on%20Automated%20Vehicles.

will be extremely unhappy with it, and the sudden braking could potentially lead to secondary crashes involving the following vehicles. Achieving the combination of very low false negatives and false positives requires that the sensor signal processing be able to classify targets with extremely high confidence, which is extremely difficult, considering the essentially unlimited diversity of the target objects that could appear in front of a road vehicle. Although no system will be perfect, the advent of automated emergency braking in 2006 and its proliferation across many car models since then indicate that extremes in false positives have been avoided sufficiently to gain some degree of user acceptance and acceptable system performance. Vehicle OEMs introduce this system on more vehicle models every year. For situations at high speeds, the system is designed to provide a warning sufficiently ahead of the hazard to give the driver an opportunity to handle the situation; if not, emergency braking activates when a collision is assessed to be inevitable, so as to reduce the energy in the collision. Even at the warning stage, the systems must be acceptable to the customer in avoiding false positives; however, the requirements for false negatives are less demanding than they will be for more highly automated systems because the driver is still available to detect the large majority of hazards.

- The threat assessment function at the downstream end of the perception process needs to predict future motions of a target as well as its current locations in order to enable the automated vehicle to take appropriate evasive action. A ball bouncing across the path of the vehicle may be followed by a child running into the street to retrieve the ball. A pedestrian standing at the edge of the road is not a relevant hazard, but if he or she is starting to cross the road, the potential for a hazardous situation is created, depending on trajectory and speed of motion. To some degree, these challenges have been addressed by pedestrian warning and detection systems now on the market, including emergency braking for pedestrians, bicyclists, and animals. Although these systems are not perfect, several vehicle manufacturers have deemed them good enough for product introduction. In contrast to automated driving, however, these systems only augment the driver's vigilance and collision avoidance capabilities rather than supersede them.

For high levels of automated driving, it is not clear whether these challenges can be met with the sensor technologies currently available, given the inherent limitations of each of those technologies. A perfect system is not possible; however, current collision warning products exhibit threat detection and response behaviors that represent a start toward meeting future needs. Because products continue to be rolled out across the industry, it is clear that internal OEM criteria for acceptable operation are being met, generally speaking, but there has not been an opportunity for independent assessment of how strict those criteria are.

It may be necessary to advance to imaging radar, which can provide information on range and range rate for all objects surrounding the sensor (vehicle) under all weather conditions and without interference from precipitation. Imaging radar could potentially combine the advantages of current radar, lidar, and video technologies but will require extensive development effort to become a viable alternative at an automotive price point.

3.7 Software Safety

The most daunting of all the technology challenges is in the field of software safety. Currently there is no available method for efficiently developing, verifying, and validating software that can be ensured of being dependable enough to make safety-of-life critical decisions. The complexity of software, especially for an application as complicated as automated driving, is such that it is not possible to prove its completeness or correctness analytically. Exhaustive enumeration or testing is also impossible because of the curse of dimensionality (the number of possible combinations of paths through the software logic, given the diversity of the input measurements that the software will encounter in driving, is too vast to be manageable).

Analytical methods have been applied to verification and validation but only on extremely simple example problems, and even those have been found to become extremely complicated. The existing analytical methods are not scalable to a problem of the complexity of automated driving. In practice, software verification and validation are currently done by using brute-force methods that are extremely costly and time consuming to apply.

Despite the prevalence of software-intensive devices in modern life, the robustness and dependability of software does not approach that of the hardware platforms that host the software. Consider the relative incidence of software versus hardware faults in desktop and laptop computers or smart phones. The automotive example is somewhat different, in that the vehicle does not need to host unvetted software from uncontrollable external sources, but the inherent difference in complexity of software and hardware remains. To our knowledge, there have been no examples of safety-of-life critical decisions having been assigned to software systems. Even though software is used to analyze medical data and make recommendations about treatments for patients, a physician must examine and approve those recommendations before a treatment is given. In automated road transport, decisions about vehicle maneuvering can have similar safety-of-life consequences, and major advances in software engineering (and extensive testing to prove validity) will be required before those decisions can be trusted to software in a real-world application.

If a fully sufficient solution is not available, the question of what constitutes "good enough" is raised. In the domain of product development in a competitive environment (the automotive industry), each system developer is answering this question individually. Techniques for addressing software safety that build upon extensive techniques already developed for active safety systems are under active development at this time. The specifics of these approaches are proprietary and not published. At the same time, public agencies with responsibility for protecting the public safety have to exercise their own due diligence regarding the safety claims of system developers rather than simply accept those claims at face value. Because of the technical complexity of automation software and the absence of specific reference standards, it is difficult for an external entity (independent test lab or government agency) to independently verify the safety of automation software, which thus remains one of the primary unresolved technological challenges. The situation is further complicated by aftermarket systems offered by new market entrants that may not have a long legacy of developing robust and safe complex vehicle control systems.

Methods put forth by Daimler include extensive simulation for verification of control algorithms and rule compliance plus a systematic search for rare functional deficits (instead of just driving large numbers of test kilometers).[18] Specific functions noted are

- Continuously assessing and adapting to external conditions and rules,
- Judging reliably whether limits of vehicle automation performance are close,
- Announcing the end of automated driving mode early enough for the driver to take over, and
- Bringing the vehicle to a safe stop if the driver should fail to do so.

In principle, this seems like a logical approach, but the devil is in the details, and if the approach is not executed with complete thoroughness it will not be able to lead to a safe system. Validation of the simulations to be used as the baseline for verification of the control system is a serious challenge in itself, because any simulation is a simplified representation of reality rather than the complete reality, and the safety challenges are typically associated with the corner cases that are most difficult to capture in simulations.

Following are European projects that directly address this challenging field:

- PEGASUS (Germany; project for establishing generally accepted quality measures, tools, and methods as well as scenarios and situations for release of highly automated vehicle functions), which seeks to define an extensive set of traffic situations with methods and thresholds to assess controllability;
- The Response 4 project of Automated Driving Applications and Technologies for Intelligent Vehicles (AdaptIVe, European Union), which focuses on safety validation and technical system limits as well as on legal aspects for the introduction of automated driving; and
- Test Environment for ADAS and Automated Driving Systems (TEAADS, European Union), which aims to improve testing methods and testing automation for highly automated vehicles with high efficiency.

This research is very useful in addressing several of the important issues discussed here; these projects could be a starting point for more extensive transatlantic collaboration.

3.8 Ethical Considerations in Computer Control

The media frequently refer to no-win scenarios in which any decision made by the automated vehicle results in death. Who lives and who dies—the occupants of the automated vehicle or someone outside the vehicle? Although such an event would be rare, it cannot be left to chance. This issue has given rise to research based in ethics and philosophy on the one hand and work within the auto industry to begin developing implementable ethics in software on the other hand. The latter research involves translating a predefined ethics of driving systematically into computer code so as to define how an automated vehicle behaves in complex driving situations in which every possible alternative leads to some type of harm. Individual automakers are active in this area, but for the industry as a whole this is a research and development topic still in the early stages.

3.9 Precompetitive Research Opportunities

The technical issues reviewed here primarily require significant research investments. Significant differences of opinion exist about the extent to which fundamental breakthroughs will be needed in several of these topic areas. In-depth interactions of international experts could make important progress toward convergence on defining the critical research problems and a roadmap for resolving them. Key issues could be addressed through precompetitive research activities involving public- and private-sector organizations, as has been successfully done in the development of

[18] Schöner, H.-P. Challenges and Approaches for Testing of Highly Automated Vehicles. Presented at CESA 3.0, Paris, Dec. 3–4, 2014.

crash avoidance systems. There should be opportunities for research collaboration and research coordination between the European Union and the United States in most of these areas before the work advances to the stage of development of potentially competitive commercial products. The technological challenges do not stop at national or continental boundaries, and the solutions will be needed in all countries. The solutions may be more difficult to implement in the United States because of its less consistent and less-well-developed roadway infrastructure, but the technology suppliers are global organizations serving global markets (including less developed countries with even more challenging traffic and infrastructure conditions).

4 Nontechnological Issues

A wide range of nontechnological issues needs to be addressed to facilitate the implementation of road transport automation systems. Automation violates many of the assumptions on which existing policies and practices are based, so it requires their fundamental reexamination and reconsideration, which can be intellectually and politically challenging. Complicated interactions with the competitive forces in the automotive industry will be involved, as will the various institutional and regulatory perspectives that derive from diverse regional cultures.

Resolving policy and regulatory issues can be difficult because automation is a source of apprehension and uncertainty among the general public, the media, and elected officials, just as it is also a source of wonder and hope for the future. The relative mix of these positive and negative perceptions varies greatly from person to person, which accounts for much of the uncertainty about how these issues will be resolved. It should be possible to minimize negative perceptions, if not entirely to eliminate them, when automation technology matures to the level that developers can offer convincing demonstrations and satisfactory assurances of the safety of automated driving systems to the market and to public agencies. That is likely to be a high bar for the more highly automated systems to meet.

4.1 Public Policy Issues

Public policies associated with the operation of road transport vehicles have until now been based on the reasonable assumption that a human driver is controlling the motions of the vehicle and is responsible for ensuring its safety. With the higher levels of automation, that assumption is of course no longer valid. This change has the largest influence on state policies regarding road traffic regulations, known colloquially as the rules of the road. Topics that become ripe for reconsideration include the following:

- Which aspects of automated vehicles should be regulated at the national level and which at the state or regional level?
- Should driver licensing and testing requirements be changed for automated vehicles?
- Should people who are not qualified to drive conventional vehicles (e.g., those who are too young, too old or infirm, or impaired by substance use) be authorized to travel unaccompanied in automated vehicles?
- Should an automated vehicle be permitted to operate on all public roads, or only on specific subsets of the road network? If the latter, what challenges would arise in enforcing this stipulation?
- What criteria should be applied to determine whether an automated vehicle is eligible to be registered for use on public roads?
- What motor vehicle codes should be modified to account for the enhanced capabilities of automated vehicles (e.g., regarding driver distraction, alcohol and drug use, providing information to law officers after crashes)? For instance, an important issue for deployment of truck platooning relates to current regulatory language stipulating allowable following distance.
- Should public agencies invest in modifying their roadway infrastructure to better accommodate the needs of automated vehicles? If so, how should they prioritize these investments relative to investments in their more traditional roles?
- Should government agencies force more uniform standards to be applied to the roadway and roadside infrastructure to simplify the environment for automated vehicles?
- Should new organizational and financing models be used to facilitate infrastructure–vehicle cooperation for automated vehicle operations? This cooperation may include professional capacity building focused on required skill sets (technological and financial) within infrastructure agencies.
- Should public agencies provide financial incentives for purchase and use of automated vehicles (e.g., preferential toll rates, tax rebates)?
- How should law enforcement interact effectively with automated vehicles?

As an interesting near-term case study, automated valet parking (which may be on the market as soon as 2016) raises questions in the policy arena. These questions are likely to touch on the jurisdiction of national, state, and city governments. For example, if vehicles are moving around empty in a shopping center parking lot, will pedestrians feel threatened? How can the needs of public safety and the vehicle market be balanced in the definition of new regulations or certifications?

In the longer term, if vehicles are able to operate on most of the road network without drivers, there is potential for significant impacts on land use, urban development patterns, and workplace practices. Parking locations could be decoupled from the origins and destinations of the travelers, freeing up valuable urban space that is currently occupied by parking facilities. If drivers are relieved of the driving task to do other things while making their trips, the disutility of travel time would be reduced drastically and people's productivity could be increased significantly (as it is currently for the high-tech employees commuting on their employers' private coach buses in Silicon Valley). The choice of residential location could be decoupled from the location of employment. Personal vehicles could become mobile offices for people who need to travel from place to place during the work day, such as sales people. The implications for land use and travel demand are highly uncertain, potentially significant, and in need of careful study.

The International Transport Forum of the Organisation for Economic Co-operation and Development acts as a strategic think tank for transport policy. The forum created a corporate partnership board for dialogue with business. Within this structure, it undertook a study of vehicle automation technology from a policy perspective. Key insights were as follows:

- Automated driving comprises a diverse set of emerging concepts that must be understood individually and as part of broader trends toward automation and connectivity.
- Uncertainty on market deployment strategies and pathways complicates the regulatory task.
- Incrementally shifting the driving task to machines and algorithms and away from people
  - Will require changes in insurance and
  - May have an impact on what information developers and manufacturers of automated vehicles share and with whom.
- Regulators and developers should actively plan to minimize legacy risks by
  - Enabling monitoring of older models of automated vehicles and
  - Making use of over-the-air software updates.

Questions going forward were as follows:

- Treat automated vehicles specifically or generally?
- Let policy lead or lag?
- Privilege uniformity or flexibility?
- Emphasize ex ante or ex post regulation?

4.2 Legal Issues

Prior to the advent of automated driving, challenging issues are likely to arise in determining how responsibility is shared when failures occur in cooperative systems that involve multiple vehicles and infrastructure devices. Automated driving will complicate this further. In discussions with vehicle OEMs, a general opinion is emerging regarding operations in the United States:

- Automated driving will shift liability from the driver to other players.
- No major overhaul of product liability is needed; OEMs will not be liable for misuse.
- Instructions to the driver are very important.
- The law needs to accommodate driver use plus nondriving activities. Clarity is needed about driver duties in Level 3 automation and above.
- The spread of no-fault insurance (available in some U.S. states) could be helpful; however, vehicle OEMs are still open to civil liability lawsuits. Therefore, no-fault insurance is not a panacea.

The Vienna Convention on Road Traffic, written before automated vehicles were envisioned, presents potential roadblocks to automated driving on EU roads.[19] (The U.S. is not a signatory to the convention.) Further, the United Nations Economic Commission for Europe (UNECE) defines additional factors that may limit automated vehicles. The automotive industry is working with government to potentially amend these documents. The main items subject to modification are as follows:

- Every moving vehicle must have a driver, who shall be able to control the vehicle at all times (Vienna Convention).
- Drivers shall at all times minimize activities other than driving (Vienna Convention).
- Drivers shall at all times be able to perform maneuvers required of them; when adjusting vehicle speed they shall pay attention to the surrounding situation; they shall slow down and stop when circumstances require.
- Automated steering above 10 kilometers per hour is not allowed (UNECE Regulation 79).

Proposed amendments, which have not yet been ratified, call for language similar to the following: "Vehicle systems shall be considered as in conformity with the regulation when they can be overridden or switched off by the driver." It is currently not clear if or when new amendments and interpretations will be in place to clear the way for automated vehicle operation.

[19] Convention on Road Traffic, Vienna, 8 November 1968. https://treaties.un.org/Pages/ViewDetailsIII.aspx?src=TREATY&mtdsg_no=XI-B-19&chapter=11&Temp=mtdsg3&lang=en.

4.3 Vehicle Certification and Licensing

One of the biggest challenges to the deployment of road transport automation involves determining how to decide whether a specific vehicle automation system is safe enough that it should be permitted to operate on public roads. This question has two dimensions, each posing different challenges: (*a*) setting the safety requirement and (*b*) verifying that that safety requirement has been met by the specific vehicle system.

There appears to be widespread agreement that an automated vehicle must be no less safe than the human drivers of today's road transport system, although some have suggested that it should be safer by some multiplicative factor (factors from 2 to 10 to 100 have been proposed at various times). Some have also suggested that the safety of an automated vehicle should match that of a highly skilled and experienced driver (rather than an average driver) or even that of a modern railroad system. Even the least demanding of these goals (the safety of the average driver today) will be technologically challenging. One way of quantifying this average safety is to rely on existing traffic safety statistics as the baseline. On the basis of U.S. statistics for 2011, this level of safety corresponds to a mean time between fatal crashes of 3 million vehicle hours of driving and a mean time between injury crashes of 65,000 vehicle hours of driving.[20] (Because rates of property-damage-only crashes are not well documented, it is difficult to estimate the analogous statistics for those crashes.) Fatality rates for European countries range from half that of the United States (in northern Europe) to twice that of the United States (in eastern Europe)

After the safety requirement is determined, the bigger challenge is in identifying a method for verifying that a specific vehicle automation system can actually meet that requirement. Because unsafe events are so rare, naturalistic testing would require huge amounts of exposure data to obtain statistically valid samples and therefore would be unaffordable in resources and calendar time. Automated driving is such a new field that no industry or government performance standards have been defined yet, so there is no baseline standard that can be cited as the point of reference for certification. Several procedural alternatives have been suggested, but they all pose various problems, including the following:

- Manufacturers self-certify that they meet the requirement, without publicly documenting the basis for their certification. This provides no comfort to skeptics, who do not trust the veracity or the methods of the manufacturers. However, this technique has been adopted by the European New Car Assessment Program (Euro NCAP) for advanced active safety systems.[21]
- Manufacturers self-certify that they meet the requirement and make the supporting data available for public review and approval. This process would expose manufacturers' intellectual property and would be very complicated for independent reviewers to assess.
- Manufacturers document their functional safety design process for review and approval by a third party (could be an independent expert or a public agency employee reviewer). This focus on the process cannot uncover faults in a specific design.
- Manufacturers submit their detailed designs (possibly even their source code) for review by a third party expert. This process would be costly and time consuming and would potentially expose manufacturers' intellectual property.
- Manufacturers submit their vehicles for an acceptance test by the public agency, analogous to a driver's licensing test. The design of that test would be very challenging and would be expensive to conduct if it is sufficiently comprehensive to be a meaningful test of the safety of the vehicle under potentially hazardous conditions.

A complicating factor will be the advent of over-the-air software updates that are now used to a limited extent (Tesla) and are likely to become more common. Although it is reasonable for system developers to learn from experience and provide updated software, doing so potentially would raise the need to recertify after each update, as updates can introduce new faults.

This is a topic that will benefit from careful consideration by the international experts to determine whether it is possible to learn from the best practices in all countries, including in other domains, to identify an approach that can provide credible assurance of safety at a tractable level of complexity.

4.4 Public Acceptance

The J. D. Power 2014 U.S. Automotive Emerging Technologies Study surveyed more than 15,000 people in the United States about a wide range of automotive technologies.[22] Respondents were asked to rate their interest in automated driving, assuming a $3,000 option price. A total of 24% of the drivers surveyed were interested (up from 21% in 2013). Preferences skew toward the

[20] Shladover, S. E. Technical Challenges for Fully Automated Driving Systems. *Proc., 21st ITS World Congress*, Detroit, Mich., Sept. 7–11, 2014.

[21] Euro NCAP Advanced Rewards. http://www.euroncap.com/en/ratings-rewards/euro-ncap-advanced-rewards/.

[22] Youngs, J. 2014 U.S. Automotive Emerging Technologies Study Results. J. D. Power, May 2014. http://www.jdpower.com/cars/articles/jd-power-studies/2014-us-automotive-emerging-technologies-study-results.

younger generations; by age group, those interested were as follows:

- 41% Generation Y (born between 1977 and 1995),
- 25% Generation X (born between 1965 and 1976),
- 13% Later Boomers (born between 1954 and 1964), and
- 13% Early Boomers (born between 1947 and 1953).

Pricing can be referenced to today's most advanced vehicle technology packages; 2014 pricing for technology packages bundling navigation, infotainment, and safety (including adaptive cruise control, lane-keeping assist, blind spot detection, and emergency braking) was in the range of $3,000. The J. D. Power representative price was in that range. Automated systems will require a degree of redundancy of safety-critical systems and components that could bring the price above this range; however, the price to the customer is difficult to predict, as it is heavily influenced by market factors.

As to uptake rates, various predictions have been made regarding diffusion modeling. Uptake is more difficult to predict than for previous automotive innovations because no other technology ever offered in cars has allowed drivers to do something else with their brain.

4.5 Insurance

Insurers will see their business change as crash avoidance systems proliferate and if the predicted crash reductions occur on the basis of the use of these systems. The resulting reduction in crashes, coupled with the highly competitive nature of the industry, will put pressure on premiums. The industry as a whole (in monetary terms) may shrink.

As automated driving comes, crashes may be reduced further and new crashes caused by the automation may arise. Additionally, human drivers will still be on the road for the foreseeable future, meaning that they could crash into an automated vehicle. The parties in any litigation become the driver of the crashing vehicle, the owner of the vehicle that is struck, and, potentially, the vehicle manufacturer if either vehicle was in automated mode at the time. New business structures for spreading risks will need to be developed. During periods when the automation system is engaged, the insurance premium may in effect be paid by the manufacturer.

Event data recorders that capture precrash data exist today and are expected to evolve to capture more comprehensive data as automated driving systems become available. The evolution of event data recorders will make assigning fault easier than it is today.

Insurers historically have focused on driver performance. Now it is becoming necessary to also understand vehicle performance (the presence and performance of driver assistance and automation functions on board) to more completely assess (reduce) risk.

4.6 Benefits and Impacts

The impacts of automated road transport will be diverse, complex, and highly uncertain because it will affect so many aspects of transport system performance, especially at the higher levels of automation. Any prediction of impacts will have to be based on assumptions about many issues that remain highly uncertain and should therefore only be subjected to sensitivity analyses rather than definitive predictions. The following questions are sorted into those that are market oriented and those that are societally oriented:

- Market-oriented questions:
  - Development trajectories of the automation technologies—what capabilities will become technically feasible in what years and how much will they cost?
  - Development of the market for automated transport systems—how much will customers be willing to pay for each capability?
  - How will the degree and extensiveness of infrastructure support affect market introduction of higher-level automation systems?
  - What vehicle performance characteristics will customers desire?
- Societally oriented questions:
  - How much cooperative infrastructure support will be available to facilitate the use of automation, and where will it be available?
  - For vehicle performance characteristics that customers desire, how will that vehicle performance influence traffic flow capacity and stability?
  - How much reduction in energy and emissions will be achievable with the vehicle performance characteristics that customers desire?
  - How safe will automated transport systems actually be in practice after their own internal failures are accounted for?
  - How will pedestrians and bicyclists interact with fully automated vehicles that have no human drivers?
  - How will public preferences for housing evolve, and what impacts will that evolution have on future urban form (i.e., trends in densification versus sprawl)?
  - How will employment patterns change, and what does that mean for commute trips to workplaces versus telecommuting?

– What is the elasticity of travel demand with respect to travel time when that travel time can be spent doing whatever the traveler wants to do rather than driving?

– How will the growth of online shopping affect urban goods movement needs?

Depending on the answers to questions such as these, the impacts of automation could vary greatly, ranging from large growth in vehicle miles traveled, with concomitant adverse impacts on congestion, energy use, and emissions, to new urban forms with reduced traffic impacts and improved quality of life.

5 Business Models and the Roles of the Public and Private Sectors

The United States and the countries of the European Union have widely varying traditions and practices in their relationships between the public and private sectors. Approaches that fit well within one country's established business and legal frameworks may not fit well at all in another country. Regardless of country-specific issues, the definition of business models and the relationship between the public and private sectors in the deployment and operation of road transport automation eventually comes down to identification of who gains and who pays. When the costs and benefits are naturally distributed equitably among the stakeholders, progress can be swift and smooth, but business models become challenging when there is a mismatch between who gains and who pays. In these cases, financial transfer schemes typically need to be created to redress the mismatch, and these schemes can become complicated, especially if political decisions need to be made about taxing stakeholders who gain to compensate others who lose.

5.1 Private Vehicles and Public Road Infrastructure

The most common model for road transport involves privately owned and operated vehicles that use publicly owned and operated roadway infrastructure. The costs of the roadway infrastructure are financed through a combination of user fees charged to vehicle operators (fuel taxes, vehicle licensing taxes, and tolls) and general tax revenues. Some countries have stretched the roadway ownership model to include private, public–private, or quasi-public ownership and operation of some sections of their primary road infrastructure (e.g., bridges, tunnels, turnpikes, major highways). In these cases, the user fees need to be allocated more precisely to reflect the amount of usage of the facility by each user.

At the higher levels of automation, where there are technical reasons for vehicles and roadway infrastructure to be well matched to each other, there are opportunities to change the traditional business model to a more closely integrated one. Vehicles and roadway infrastructure could be owned by a common entity (public, private, or public–private partnership), and a transportation service could be offered to end users, who would pay directly for each trip or each period of usage rather than purchasing a vehicle.

For this vision to come about, all parties must establish credibility as reliable business partners who are committing to invest at a certain level and within a specific time frame. In the past, such a commitment has been challenging for the public sector because of limitations on and the unpredictability of budgets and because of changing priorities. On the private-sector side, it is challenging for the industry to speak with one voice, owing to the varied actors at play—namely, individual automakers and truck manufacturers (the incumbents) plus potential new entrants.

5.2 Types and Levels of Infrastructure Support for Automated Vehicles

The business models that are likely to become attractive will depend on the type and level of infrastructure support that automated vehicles will need to reach a beneficial level of system performance. Examples of infrastructure support include the following:

Level A. Digital road infrastructure (e.g., digital maps or other static databases about the driving environment) and dynamic information (e.g., real-time data about lane closures, work zones, incidents, and traffic conditions);

Level B. I2V and V2I communication of data relevant to the dynamic driving task;

Level C. Improved road markings, roadway lighting, and signage;

Level D. Changes to civil infrastructure (e.g., special barriers to protect the automated vehicle's path, segregated lanes or ramps, or completely segregated rights-of-way); and

Level E. Standards for asset management, that is, the state of good repair of supporting infrastructure, including pavement and traffic control devices.

Any of these levels of infrastructure support could be provided by public-sector agencies working within their traditional areas of responsibility. Level A infrastructure support could easily be provided by private companies operating within their current business models, and Level B support could also be provided publicly or privately, although the latter would require some policy changes by public agencies to make the underlying data readily available to private entities in real time. At Levels C and D, the functions are much more closely tied to traditional public-sector responsibilities, and the investments of capital and operating expenses are considerably higher as well. Providing these types of infrastructure support privately would represent larger changes from current practices in most jurisdictions and larger financial commitments.

In cases when Level C or Level D infrastructure support, or both, makes a large difference in the capabilities of an automated vehicle system, and especially when this support makes the difference between the technical feasibility or infeasibility of a road transport automation service, there is an opportunity for an integrated vehicle–infrastructure business model. One organization (such as a partnership between a private road operator and vehicle manufacturers) could invest in both vehicle and infrastructure elements (as railroad companies do today) and sell the resulting transportation service to the end users. This idea could make financial sense when the combination of vehicle and infrastructure elements enabled a significantly enhanced level of transportation system performance (such as dramatically increased capacity or speed or the introduction of a new service such as automated repositioning of unoccupied vehicles). The caveat about reliable business partners noted previously applies in this context as well.

5.3 Roadway Infrastructure Deployment Challenges

Roadway infrastructure owner–operator agencies are underfinanced in most countries and are challenged to maintain the roadway infrastructure that they already own. It is difficult for them to finance expansions or enhancements of their facilities, even when the benefit–cost ratios and return on investment estimates are favorable. Addition of sophisticated technology elements to their portfolios is also challenging because the staff of most infrastructure agencies come from traditional civil engineering backgrounds and do not have the technical expertise to effectively acquire, operate, or maintain information technology systems. The infrastructure development process, which involves public policy makers and their constituents, is typically slow and deliberative, with multiple layers of checks and balances and reviews for policy, funding, and environmental impacts. This means that the process needs to be started early enough to enable infrastructure changes to be implemented by the time they are needed.

In the event that onboard systems alone cannot provide sufficient performance for a higher level of automation (the likelihood of which is subject to significant differences of opinion), the financial and technological limitations of public roadway infrastructure agencies could become the pacing factor in limiting the rollout of the more highly automated vehicle systems in some countries or regions. Locations that have the ability to upgrade their infrastructure are likely to experience the benefits of the higher levels of automation earlier, but widespread deployment will be limited by lagging jurisdictions. In this situation, new business models that facilitate private investment on the roadway infrastructure side could make a large difference. The private market for vehicles with higher automation capabilities is likely to be stunted until those vehicles are usable over a large fraction of the roadway network. How enthusiastic will the car-buying public be about paying extra for features that can only be used when driving in wealthier political jurisdictions?

5.4 Business Models for Financing Infrastructure Improvements

In situations in which the lack of infrastructure support is impeding the transportation system improvements that could be gained from automation, there should be a financial incentive to seek or develop new business models for financing infrastructure improvements. The financial incentive comes from the willingness of end users to pay to receive the benefits of those improvements (e.g., travel-time savings, stress reduction, ability to do other things safely while driving, avoiding vehicle ownership expenses). The new business models could include

- Joint public–private financing of infrastructure modifications;
- Charging for road use (tolling or distance-based pricing), perhaps with prices dependent on the fraction of the system capacity that each user consumes;
- Formation of a new transportation enterprise (or partnership) that owns the vehicles and their running way and charges users for the distance or time that they use the vehicles;
- New public–private partnership arrangements yet to be defined; and
- Investments from new types of organizations, such as information service providers who are willing to pay to gain improved access to the eyeballs of drivers who are no longer driving.

The United States and the European Union should be able to learn from each other's experiences with any new business models so as to help each other find the most promising alternatives to suit their needs.

6 Conclusions

Road transport automation has the potential to make profound changes to the operation of road systems throughout the world. It is currently unclear how long it will take to realize the potential changes from each level of automation because there are so many uncertainties about the technologies and the policy environment in which they need to be deployed. These uncertainties represent great opportunities for research and development cooperation between the European Union and the United States, which both stand to gain from the products of the research and development work. The challenges are so large that neither region can expect to resolve all of them on its own, and progress will be accelerated through sharing of knowledge and resources.

Information exchange about road transport automation is improved when common terms of reference can be relied on in communications. For example, confusion about the state of automation development and capabilities is minimized when descriptions of automated driving systems are qualified in terms of their goals, the relative roles of the driver and the automation system, and the type of environment(s) in which the automation functions can be used.

Some fundamental aspects of road transport automation remain controversial and subject to differences of opinion that are not easily resolved. These questions include the following:

- To what extent do in-vehicle automation technologies need to depend on support and cooperation from the roadway infrastructure and other vehicles?
- What level of public-sector involvement will be needed to provide infrastructure support for automation, if needed?
- Can the higher levels of automation be implemented solely on the basis of enhancements to technological capabilities that already exist, or will their implementation require fundamental breakthroughs in some technological fields?
- What roles should national and regional or state governments play in determining whether automated driving systems are safe enough for use by the general public?
- How safe is safe enough?
- How can an automated driving system be reliably determined to meet any specific target safety level (sufficient for certification)?
- Should designs of automated driving systems be required to inhibit abuse and misuse by drivers, or should the proper use of the system be left to the responsibility of the individual driver?
- Are new business models for interactions between the public and private sectors in road transport necessary for the successful implementation of higher levels of automation? If so, what are the most promising such models?
- How will road transport automation change the nature of public transport services? Will those changes lead to more or less use of public transport, and will societal goals for mobility be enhanced or degraded?
- What will be the net impact of the automation of road transport on vehicle miles traveled and on the energy and environmental impacts of road transport?

Some of these issues derive from fundamental philosophies about the roles of the public and private sectors, but others are susceptible to resolution through research. Some specific research areas have been suggested in both technological and nontechnological fields. Technological research is needed on a wide range of topics, listed here in order of increasing level of difficulty:

1. Wireless communication technologies sufficiently robust to support automation;
2. Highly dependable methods of vehicle localization;
3. Human factors and driver interfaces to support mode awareness and safe mode transitions;
4. Practical methods for developing and continually updating high-definition map data to support automated driving;
5. Incorporation of ethical considerations into control system design;
6. Fault detection, identification, and accommodation methods to enhance safety when fault conditions arise;
7. Cybersecurity methods to protect against attacks (applicable to all modern vehicles, not only those with automated driving capabilities);
8. Environment perception technologies that can provide extremely low rates of false positive and false negative hazard identifications; and
9. Software safety design, development, and verification and validation methods that can be implemented affordably.

These topics should be fruitful ones for EU-U.S. cooperation on precompetitive research to develop the fundamental technical capabilities.

In the nontechnological areas, the differences between EU and U.S. situations are likely to be larger, so the fit may not be as close. However, studies of the contrasts between the EU and U.S. situations can also be enlightening, even if the most appropriate approaches turn out to be different in the end. Nontechnological topics for investigation include the following questions:

- Which aspects of automated vehicles should be regulated at the national level and which at the state or regional level?

- Should driver licensing and testing requirements be changed for automated vehicles?
- Should people who are not qualified to drive conventional vehicles be authorized to travel unaccompanied in automated vehicles?
- Should an automated vehicle be permitted to operate on all public roads or only on specific subsets of the road network? If the latter, what challenges would arise in enforcing this stipulation?
- What criteria should be applied to determine that an automated vehicle is eligible to be registered for use on public roads?
- What motor vehicle codes should be modified to account for the enhanced capabilities of automated vehicles (e.g., codes regarding driver distraction, alcohol and drug use, providing information to law enforcement officers after crashes, and so forth)?
- How should public agencies make decisions about prioritizing investments in modifying their roadway infrastructure to better accommodate the needs of automated vehicles?
- Should government agencies force more uniform standards to be applied to the roadway and roadside infrastructure to simplify the environment for automated vehicles?
- Should new organizational and financing models be used to facilitate infrastructure–vehicle cooperation for automated vehicle operations?
- Should public agencies provide financial incentives for purchase and use of automated vehicles (e.g., preferential toll rates, tax rebates).
- How should law enforcement interact effectively with automated vehicles?
- How should legal issues such as vehicle codes and the Vienna Convention be addressed to minimize interference with the implementation of automated driving systems?
- Should laws be modified to ease liability concerns for the implementation of automation?
- How should minimum safety requirements be determined for automated driving systems?
- How should a new automated driving system's compliance with minimum safety requirements be determined?
- Who should certify the safety of automated driving systems?
- How much will the public be willing to pay for various levels of automated driving systems?
- How rapidly will the market grow for the various levels of automated driving systems?
- How will the insurance industry have to adapt in response to changes in crash rates and causes after the introduction of automated driving systems?

As these issues are studied, new ideas are likely to arise about how to change the traditional split between privately developed, owned, and operated vehicles and publicly developed, owned, and operated roadway infrastructure. Answers to some of the questions raised in this paper could be developed through new forms of public–private cooperation that still need to be designed.

APPENDIX B: COMMISSIONED WHITE PAPER 2

Road Transport Automation as a Societal Change Agent

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White Paper 2 is a companion to White Paper 1, "Road Transport Automation as a Public–Private Enterprise." White Paper 1 examines transport automation as a diverse technological and policy opportunity to systematically address the challenges of our current transport system; in contrast, White Paper 2 considers the changes involved for individuals, companies, governments, and society at large.

Automation may have dramatic impact for road transport. This paper gives an overview of the potential impacts of automation but also provides a critical examination of the additional costs that may be involved in the new technology. The rate of introduction of automation—and its breadth of application—will determine its overall impact on society, both positive and negative. Wide application of automation in transport could represent a significant force for societal change, perhaps on a level with personal communication devices.

Section 1 of this paper sets the scene, while Section 2 examines the impacts, benefits, and costs in the short and medium term, where medium levels of automation can be reached. Section 3 addresses the long-term changes that can be expected with high levels of automation. Finally, Section 4 draws conclusions and enumerates open questions.

1 Setting the Scene

In the near term, technological changes are likely to be incremental. There are two tracks of development. The first has a focus on increased assistance to the driver in motorway driving with a gradual evolution toward fully assisted motorway driving in at least some situations. The second track focuses on the development and deployment of low-speed urban shuttles that have the capability for full automation (initially in circumscribed environments). Likewise, the impacts of such automated driving are likely to be incremental.

Driving will be assisted in some locations on those vehicles that are equipped with the capability. It is likely that the motorway systems will be delivered first on high-end vehicles, that the first systems will be mainly autonomous (i.e., they will not require connection to other vehicles or to infrastructure), and that supported operation will initially be on high-quality, well-regulated roads, that is, on motorways where the road and traffic situation can more easily be assessed by the system. A set of limitations on system usage may be imposed that will permit operation only under certain conditions—for example, in good visibility. The next step would be to extend capability to interurban roads, with urban capability being the final step. Preconditions for operation would gradually be reduced.

Once full door-to-door capability under most operating conditions is achieved, then true driverless vehicles will be available and will essentially provide a new mode of transport. That new mode is likely to be quite disruptive in terms of socioeconomic impacts, and so the provision of this new capability or service may have revolutionary as opposed to evolutionary consequences.

True driverless transport may be implemented first in shared or public transport, or both. In the near and medium term, driverless autonomous vehicles will transport passengers on streets and areas in urban communities and transport terminals. Such vehicles are already on the market from manufacturers such as EasyMile.[1]

[1] See http://www.easymile.com/.

Automated driving has many types of benefits, some direct and some indirect. The benefits originate at the individual level, in changes in the behavior of drivers and travelers with regard to driving and mobility, and conclude with benefits at the social level via changes in the whole transport system and society, in which many of the current planning and operations paradigms are likely to be transformed by automated driving. There may also be disbenefits (e.g., in intensity of travel), particularly at the social level, that could result in additional congestion and increased use of natural resources. There may also be unintended consequences. For example, the impacts on public transport are not known. Driverless vehicles could provide a means to lower-cost service provision, but the availability of automated cars could lead to more car travel at the expense of collective transport.

2 Near and Medium Term

In this period, most of the changes are likely to be evolutionary, with a gradual introduction of higher levels of automation, particularly for privately driven vehicles. Additionally, urban pods may operate in limited and perhaps segregated environments.

There are still some major issues in technology and design that need to be resolved, including the following:

- Determining whether automated vehicles will have maneuvering capability, for example, the capability to carry out lane changes (some original equipment manufacturers envisage such capability within a few years, but it is as yet unclear under what circumstances vehicles will have the authority to change lanes);
- Maintaining driver situational awareness at medium levels of automated driving as the technology moves toward full automation, given that humans tend not to maintain attention over long periods of supervisory control;
- Ensuring safety in mixed traffic, including when vehicles have different levels of automation; and
- Ensuring the safety of vulnerable road users in interaction with automated vehicles (on motorways, interaction with motorcycles is the main issue).

These issues are extensively discussed in White Paper 1.

2.1 Benefits

2.1.1 Individual Benefits

For an individual, access to infotainment and the possibility to work or relax or just be connected while driving is likely to be the major motivation for highly automated driving. For many, this possibility will mean a major change in their lifestyle and improvement in their quality of life. These changes could also make long-distance commuting by car more palatable and thus make possible a wider choice of residency location.

According to DFT (2015), an average driver spends 235 hours driving every year, during which he or she must concentrate on driving 100% of the time. In an automated vehicle, this journey time could be safely used however the occupant wished—working, reading a book, surfing the web, watching a film, or just chatting face-to-face with other passengers. Mohktarian (2015) has argued that the freedom to multitask is a significant factor in mode choice. It can be argued that some of the benefit of any such ability flows to an employer rather than just to the individual.

However, in some countries regulatory change would be needed to allow the use of infotainment while driving. One significant issue is the interplay between levels of automation and engagement in non-driving-related activities. Carsten et al. (2012) found that drivers were very willing to engage in nondriving activities while driving—particularly watching videos—even with Level 1 automation that provided only automated lane keeping. Admittedly, that study was carried out with a driving simulator, but it can certainly be expected that, even at the lower levels of automation (Levels 1 and 2), drivers will wish to exploit the support to use their time in a more rewarding manner.

For many individuals, the reduction of the risk of fines related to compliance with traffic rules and regulations may be a meaningful benefit. That benefit would apply also to current rules about using mobile phones and other devices while driving. There may be a need for legislation to change in this regard to accommodate non-driving-related activities under certain circumstances.

The comfort of driving may be one of the main selling points in the near term. Vehicles will be able to offer more and more automation for boring tasks; for example, long-distance driving on freeways and other highways will be supported by lane keeping combined with adaptive cruise control.

Another individual benefit resulting from the increased level of safety offered by the new systems could be potential cost savings resulting from reduced insurance premiums.

Short- and medium-term levels of automation could be attractive for elderly people, who may adopt automated driving relatively quickly unless they find it too complicated to use. It is likely that manufacturers will limit their liability by setting a series of use restrictions. A major issue is public acceptance of these systems, which may limit the freedom of the driver with a variety of warnings when the driver engages in tasks other than driving. At lower levels of automation, the benefits will be restricted, as the driver will need to be prepared at all times to take control of the vehicle.

2.1.2 *Social Benefits*

2.1.2.1 *Safety*

Effects on safety in the transitional period depend largely on the features of automation and on the penetration of vehicles with automated driving capability. One might expect some crashes on motorways to be avoided because of the fast reaction times of highly automated vehicles. There is also the potential for automated vehicles to have an effect on fatigue-related crashes, although operator sleepiness may be increased as a result of boredom in driving and of disengagement from vehicle control.

Vehicles capable of high-level automation [Society of Automotive Engineers (SAE) Levels 3 and 4] will of necessity come equipped with an array of sensors and of crash avoidance systems. Those technologies will also be available to provide driver support and crash avoidance in manual driving and in driving at lower levels of automation (SAE Levels 1 and 2). Therefore, it can be expected that these vehicles will be safer in general operation. It can also be expected that the automation aspects will provide only a small additional benefit. The general safety effects of driver support systems have been estimated in a number of studies. eIMPACT examined 12 different driver support systems and estimated their fatality reduction potential to range from 1.4% to 16.6% (Wilmink et al. 2008). The systems evaluated were

- Electronic stability control,
- Full-speed-range adaptive cruise control,
- Emergency braking,
- Precrash protection of vulnerable road users,
- Lane change assist (warning),
- Lane-keeping support,
- Night vision warning,
- Driver drowsiness monitoring and warning,
- eCall (an initiative to bring rapid assistance to motorists involved in a collision anywhere in the European Union),
- Intersection safety,
- Wireless local danger warning, and
- SpeedAlert (i.e., advisory intelligent speed alert).

It was estimated that combining all 12 driver support systems together could reduce fatality by about 50% (Wilmink et al. 2008). The overall safety impact of these systems would naturally depend on their penetration into the vehicle fleet and their relative usage.

2.1.2.2 *Efficiency and Capacity*

The reduction in shockwaves and crashes that will accompany increased driving under vehicle control should enhance capacity and efficiency. This enhancement is one of the major likely benefits of cooperation. However, there are also factors that could mitigate against enhanced capacity and efficiency:

- Long vehicle platoons in the inner or a middle lane could act as an obstacle to lane changing and therefore inhibit overtaking.
- Long vehicle platoons in the outer lanes could make merging in from an entrance ramp more difficult and could also inhibit access to exit ramps.
- Dedicated lanes for automated vehicles could reduce capacity for vehicles with only manual driving capability.
- In urban areas, any dedicated space for automated vehicles might be at the expense of other vehicular traffic. If automated vehicles require totally segregated space, then pedestrians and cyclists could also be negatively affected through loss of street space.

The provision of vehicle-to-vehicle (V2V) communication could mitigate against negative impacts on nonplatooned vehicles but would require (*a*) high penetration of V2V systems into all vehicles and (*b*) a consensus or set of regulations about operational rules, so that platoons could be broken apart to meet requests for road space from other vehicles. There is a potential need also for more general agreement or regulation concerning limitations on the operation of long platoons in weaving sections, and especially around exits and entries to the roadway. Other road sections where limitations might be needed are up gradients and places where the number of lanes reduces or is limited.

2.1.2.3 *Environment*

Any automated driving will be more fuel efficient than manual driving because automated control is smoother than manual control and is less prone to the very late reactions often exhibited by human drivers. An automated vehicle will drive in an anticipatory manner, which is at the core of ecodriving. Fuel savings will also be incurred by adherence to the speed limit in motorway driving. Carslaw et al. (2010) found that on British motorways, there would be an overall savings in fuel and carbon dioxide of approximately 6% with even loose compliance of all cars with the standard speed limit of 70 miles per hour (112 kilometers per hour). It is also possible for vehicles under automated control to be permanently engaged in a more elaborate ecodriving mode. However, environmental benefits are not likely to be substantial at lower levels of penetration and usage.

There could also be environmental disbenefits as a result of the encouragement of long-distance car journeys and of an increase in the attractiveness of long-distance commuting because the time spent in such commuting could be used more productively. An increase in long-distance commuting could promote urban sprawl, although again, the effects would be small at low levels of penetration.

2.2 Costs

The socioeconomic impacts also include costs related to additional investments caused by the move to automation. These costs are presented below on the basis of the stakeholder role in automated driving.

2.2.1 Individuals

Additional investments will likely be required for driver training and road user education, especially at the medium levels of automation. Changes to education programs will be necessary to ensure that drivers and travelers are capable of driving an automated vehicle and are fully aware of the vehicle's limitations and the consequences that those limitations impose on drivers. Drivers need to be aware of the circumstances in which they can give up control of the vehicle and when and how they should again regain control of the vehicle.

Special licenses or permits to operate an automated vehicle may be needed if research, pilots, or first-use experiences indicate licensing to be useful. For instance, Level 3 automation requiring the driver to resume vehicle control within a specific short time period could be found to be too demanding for some drivers.

2.2.2 Vehicle Owners

For the vehicle owner, automation comes at a cost. The cost of today's technology packages, which bundle navigation, infotainment, and safety (including adaptive cruise control, lane-keeping assist, blind spot detection, and emergency braking) and provide the essential elements for Level 2 automation, is in the range of $3,000 (J. D. Power 2014). Automated systems will require a degree of redundancy of safety-critical systems and components that could bring the price above this range; however the price to the customer is difficult to predict, as it is heavily influenced by market factors.

According to Öörni and Penttinen (2014), about half of the drivers polled in 2011 were prepared to pay for driver support systems (i.e., electronic stability control, blind spot monitoring, lane support system, advanced emergency braking system, speed alert, adaptive headlights). Interestingly, they found that the proportion of people willing to pay for such systems had increased by 4 to 25 percentage points since 2009. The median value of the willingness to pay for a system ranged from €300 to €500. A focus group study by KPMG (2013) found that consumers were willing to pay a 15% premium for self-driving capability.

2.2.3 Infrastructure Owner–Operators

Automated driving likely requires investments from the owners and operators of both road and information and communications technology infrastructure. For high-level automated vehicle performance in all conditions, there can be a need for

- Potential special lanes or roads reserved for automated vehicles;
- Road markings and traffic signs, which need to comply with global standards and to always be kept visible and in good condition;
- Roadside solutions to facilitate automated driving also in adverse weather and on private roads, including forest roads;
- Availability of infrastructure-to-vehicle (I2V) [and maybe vehicle-to-infrastructure (V2I)] capability; and
- A system for cost recovery.

Until the full-scale deployment of highly and fully automated driving, special lanes or roads could be needed to reap the full safety and efficiency benefits of automated driving. If automated vehicles need to interact with human-operated vehicles and vulnerable road users, the necessary functions to ensure safety will considerably reduce the mobility of the automated vehicles and the vehicle flow efficiency. In the transition period to full-scale automation, the building of special roads or lanes or reservation of special lane space for automated vehicles will lead to higher costs for road investment, operation, and maintenance. Therefore, such infrastructure will only be built if a critical mass of automated vehicles exists. However, there are dedicated lanes that could be repurposed or designated for automated vehicle operation during certain periods.

Road markings and traffic signs are necessary for the safe and efficient operation of automated vehicles. Road markings and signs need to be globally harmonized to the extent that vehicles will be able to interpret them correctly. This harmonization causes additional costs related to upgrading the markings and signs as well as to the harmonization process itself. The markings and signs should also always be kept visible and in good condition, which will also result in additional costs. For instance, in countries in which ice or snow, or both, covers roads frequently, winter maintenance costs may be doubled if automated vehicle use is desired at all times, to ensure that road surfaces are clean of ice and snow (Innamaa et al. 2015).

Roadside solutions to mark the road line will be needed to facilitate automated driving when road markings are either nonexistent or not visible. This is the case for gravel roads, narrow paved roads, and roads temporarily covered with snow, ice, or mud and also roads subject to poor visibility caused by dense fog or smoke.

Even if satellite positioning is quite accurate, it tends to drift. Accurately positioned fixed objects on a digital map may be needed to maintain the accurate position of the vehicle on the road. Therefore, road operators that wish to facilitate automated driving on the road at all times should install specific landmarks such as fixed marker posts or poles alongside the road so that these will also be accurately marked in the digital maps used in automated vehicles (Dreher and Flament 2014). Such markers are analogous to reflector posts or winter maintenance guidance sticks placed along roadsides to provide visual guidance to human drivers in adverse conditions. Naturally, the installation, maintenance, and accurate positioning of such landmarks, posts, and poles will add to the road operator's costs.

I2V and V2I infrastructure could be a component of automated driving that improves traffic efficiency. The communication infrastructure to be provided depends on the communication solution and the road and traffic environment. Dedicated short-range communication (DSRC) beacons should be available at appropriate intervals to ensure full road coverage of a specific section. In urban areas, equipping signal controls at intersections with I2V-V2I communications could be the most cost-efficient option, as the electric power and infrastructure-to-infrastructure communications would already be available. Elsewhere, the provision of DSRC could be much more costly and likely restricted to hot spots where traffic problems would require the availability of I2V-V2I communications. Cellular-based I2V-V2I communications could be the basic solution in other parts of the road networks. In the medium term, with future 5G cellular networks, no major changes in the communication infrastructure would be required, but in the existing and emerging 4G networks, some software and hardware modifications will likely be needed.

To offset the increased infrastructure costs, cost-recovery mechanisms may need to be established. In the case of public infrastructure, costs can be recovered via taxation of vehicle ownership and use or fuel. Different road user charging schemes could also be set up to cover the investment, maintenance, and operation costs for infrastructure-related elements that facilitate automated driving. Paradoxically, for policy reasons, higher charges might be imposed on manually driven vehicles to encourage the adoption of automated driving. Dynamic road user charging (e.g., via a distance tax) will be quite cost-effective to employ, as the necessary data collection, recording, and communication equipment may be readily available in the automated vehicle. Indeed, one might expect such taxation to be built into the usage fee, just as it is nowadays for taxi services.

2.2.4 *Service Providers*

To cater to the needs of the higher levels of automated driving (Level 3 or higher), various service providers will be useful in delivering

- Digital maps of sufficient quality for self-localization and environment interpretation and
- High-quality, real-time traffic information, especially for events, incidents, and congestion.

Digital maps are useful in automated driving. Local dynamic maps are used as a central point to collect information for decision. Digital map information is used as an additional sensor to provide an electronic horizon for the automated vehicle, and map information is important in supporting positioning. Hence, automated driving would benefit from highly accurate digital maps that include

- Data on fundamental road features (lanes and their widths, physical and painted features),
- Road malformations such as potholes and ruts,
- Information derived from human drivers for humanlike automation (e.g., median trajectories, average speed profile, median point of first breaking),
- Specific landmarks in the street to increase positioning accuracy (e.g., poles, shape of curbs, speed bumps), and
- Information to facilitate evasive decisions (e.g., nature of the adjacent lanes, guardrails, detours).

This information would be complemented by a feedback service from the vehicle to the map provider concerning detected discrepancies in the map data (Dreher and Flament 2014).

Provision of high-quality real-time traffic information may also add costs. High-quality information, especially on events, incidents, and congestion, is needed for extended preview information outside the vehicle sensor range (Försterling 2014). Automated driving calls for much more accurate information than that provided by today's traffic information services, especially with regard to event coverage, timeliness, and the location accuracy of the messages.

2.2.5 Automotive Industry

The costs for vehicle manufacturing may increase owing to the provision of the basic elements of automated driving:

- Extended environmental sensing,
- Accurate positioning,
- Vehicle-to-everything (V2X) connectivity,
- Need to preserve driver–occupant privacy, and
- Need to ensure security.

These costs may decrease in time with the mass production of automated vehicles, but it is likely that the relative average cost of an automated vehicle will increase as automation levels increase.

In addition, there will be additional costs related to standardization, vehicle dealer training, and vehicle servicing, at least in the transition period to full automation. Remote diagnosis and remote software updating may be a must before more automation can be introduced. Costs for vehicle servicing will also be affected because of the capability of automated vehicles to detect wear, faults, and failures. There will be low fault tolerance, which would tend to drive up maintenance costs.

There is concern as to the ability of parties other than franchised dealers to repair automated vehicles that is likely to have an impact on the costs of repair. EU legislation regarding access to repair and maintenance information requires that manufacturers commit to making repair information available on a nondiscriminatory basis to official dealerships and independent repairers alike, and certain minimum information must be included on websites as part of vehicle type approval. An automated vehicle is likely to be particularly complex and to utilize proprietary technology extensively, so manufacturers may not wish to permit or enable repair by other parties. They may be concerned that their intellectual property will be compromised if they reveal programing code, and they might also be concerned with the potential for those of criminal intent to gain knowledge that enables them to hack into vehicles (DFT 2015).

Currently, as vehicles age, repair of the more complex and expensive systems on board can become uneconomic. If there is a problem with the automation systems, such vehicles may still be able to be used in manual-only mode. It is essential that safety be maintained, but at the same time, it would be preferable to avoid premature scrapping of vehicles, which damages sustainability and negatively affects those who cannot afford new vehicles (DFT 2015).

Insurance-related costs are likely to be affected considerably for vehicle manufacturers if liability for driving is transferred from the driver–vehicle occupant to the vehicle manufacturer at higher levels of automation, starting already from Level 3. Naturally, this change in liability will be offset by the change in drivers' insurance. The overall change in insurance costs will depend primarily on the effects that vehicle automation has on the number and severity of crashes, and thereby the related insurance claims made.

2.2.6 Authorities

The authorities likely need to set up regulations concerning automated vehicles, and doing this will require resources and investments in regulation, research, and cross-border harmonization. While the deployment of automated driving may reduce the overall level of risks related to road safety, it likely will lead to a major liability shift among the stakeholders involved. The most common question raised with respect to automated vehicles is who would be held responsible in the event of a collision. There is a range of entities that may bear or share liability in road accidents:

- Vehicle drivers,
- Vehicle owners,
- Vehicle operators,
- Vehicle manufacturers,
- Vehicle suppliers and importers,
- Service providers,
- Data providers, and
- Road operators.

Each of these parties may be found to be civilly (or in some cases criminally) liable to a greater or lesser extent, depending on the exact circumstances of the situation (DFT 2015).

Concerning product liability, whether the product is judged to be defective or not is crucial. Defects include manufacturing defects, design defects, and failure to warn. Manufacturers and service providers have several liability defenses (e.g., the defect is attributable to compliance with mandatory requirements, such as domestic or European law; the defect did not exist in the product at the time the product went into circulation; or "the state of scientific and technical knowledge at the time when . . . the product [was put] into circulation was not such as to enable the existence of the defect to be discovered" (DFT 2015, 60).

Contributory negligence will also be taken into account when an award of damages to a claimant is being considered. A court would need to consider whether the driver or vehicle occupant was sufficiently aware of the potential for a collision and take into account their ability to avoid a collision. For example, the driver may have been taking advantage of the automated driving mode to undertake other tasks, so he or she either may not have been aware of an impending collision or may have been unable to react in time to intervene (DFT 2015).

Another liability-related issue is misuse of the vehicle. A vehicle manufacturer could argue before a court that the vehicle was being misused and therefore should not be found to have a defect. When a driver uses a vehicle in a manner that was clearly not intended or ignores a warning, the court might find that the vehicle was not defective (DFT 2015).

As in the case of driver support systems, the automotive industry may propose a self-certification process to show that it has performed its duty of care during the development and design process of an automated vehicle and has performed all tests necessary to show that the vehicle is safe enough for operation on public roads. These tests may be carried out in simulations, driving simulators, test tracks, and, finally, on public roads. Whether there will be an additional need for a public conformance test is yet to be determined. There is also likely to be a role for independent testing, such as that administered by the Insurance Institute for Highway Safety and the European New Car Assessment Program. Such tests can effectively create pseudostandards.

To settle liability issues in the event of a collision, automated vehicles are likely to be equipped with event data recorders. These recorders will indicate whether a vehicle was operating automatically or was in manual control at the time a collision occurred. They will also record how far in advance of a collision the mode of operation changed, a measure for which there may well be no other or better source of evidence than an event data recorder. These data will be a compelling source of information regarding what occurred and must be available to the relevant authorities for determination of liability and insurance responsibility (DFT 2015).

There are also data protection and privacy concerns with automated vehicles. Any processing of data collected by an automated vehicle should, where an individual can be identified, comply with data protection rules. Data are collected by the vehicle's own electronic control units, event data recorders, and via the different sensors on the vehicle. This information can potentially be sent from the vehicle via the Internet to remote server storage. To comply with the fair processing requirements of data protection legislation, drivers and the registered keepers of vehicles should be made aware of the data that their vehicle is collecting and the uses to which it might be put (DFT 2015). The ownership of the (big) data produced by automated vehicles needs to be resolved, as these data offer major business opportunities, even in the short term.

Theft and security measures are also required to prevent vehicle theft and "hacking," just as with nonautomated vehicles. Given the data that may be collected by a vehicle, such as GPS data and camera recordings, there may also be concerns that information on the movements of a vehicle or its location could be extracted without authorization, which would have implications for privacy issues and could potentially facilitate criminal activities (DFT 2015).

Certification and roadworthiness testing need to be developed for higher-level automated vehicles. In Europe, the vehicles will need type approval, and the framework for that approval needs to be enhanced to cover automated vehicles of all levels.

The standardization of vehicle performance (acceleration, braking, time headway, response lag) as well as the warning tone or tell-tale to inform the driver of the need to take back control are issues to be resolved. Standardization of these items is proposed to prevent confusion among the public in moving between different vehicles.

A global agreement of infrastructure requirements would be useful to clearly specify what is required to facilitate automated driving at higher levels. This agreement would include the global harmonization of road markings and signs to the extent than can be achieved.

3 Long Term

In the long term, fully automated vehicles that operate door-to-door can be expected to have full freedom of movement with many of the substantial technological obstacles having been addressed. There is the potential for a wide range of vehicles to be automated—private vehicles, pods for both personal transport (individual and shared) and goods delivery, and public transport vehicles (buses and trams).

3.1 Transformational Potential

As indicated earlier, fully automated driving would constitute a totally new mode of transport, the impacts of which are quite hard to predict (in the same way that the impacts of mass vehicle ownership and large-scale road freight on almost every aspect of social, economic, and cultural life could hardly be predicted at the onset of the 20th century).

Ridesharing via automated collective transport could secure a substantial reduction in vehicle travel by reducing single-person use. However, that reduction presumes that worries about personal security and privacy can be overcome. The means to ensure personal security will be a big factor in automated collective transport because sharing unsupervised rides with strangers will probably be unacceptable. If concerns about personal security cannot be addressed, there could be substantial reluctance to use such services, and the availability of automated door-to-door transport at affordable costs could have substantial negative environmental implications by increasing car use at the expense of walking, cycling, and collective public transport. That in turn would also result in a negative impact on public health and even life expectancy. It could have the same perverse effect on journey time that large-scale vehicle use has had in the past in industrialized countries and that motorization is now having in industrializing countries: a reduction in journey times for early adopters followed by an enormous increase in congestion and reduction in travel speeds as vehicle usage in urban areas grows.

Impacts on logistics operation could be considerable, with driverless vehicles providing last-mile service for goods movement and delivery. Both on the freight side and on the personal transport side, there would be impacts on employment. In the long run, the occupations of taxi driver, delivery driver, and tram and bus driver may be threatened. In the intermediate term, regulations on driver hours might become less of a restriction on freight operation because vehicles could be used more intensively, perhaps even for 24-hour operation. That level of operation would almost certainly require some road zones in which full automation was provided.

Fully automated vehicles may require dedicated road space in urban areas. That requirement has implications for the space remaining for other modes—automobiles, bicycles, pedestrians, and public transport.

Less land would likely be required for parking because of increased vehicle and ride sharing and reduced vehicle ownership, thereby allowing more intensive land use in urban areas. It is estimated that currently in the United States there are up to eight parking spaces for each vehicle (Chester et al. 2010).

Driverless vehicles could provide more accessibility to employment, particularly for low-income families who currently cannot afford a private car (or maybe a second car for the household) and who lack a variety of employment possibilities because of inadequate public transport. The positive social effects would be reduced unemployment and underemployment. However, there might also be negative environmental impacts, in that driverless vehicles might encourage long-distance commuting and residential dispersion.

Truck platooning and even limited-scale automated driving could reduce road haulage costs and thereby encourage even greater movement of freight by road. This could have wider implications in terms of harmful environmental effects and impact on other modes such as rail.

3.2 Benefits

3.2.1 Individual Benefits

The highest levels of automation will provide individual mobility for people without a vehicle or driving license and for those with physical impairments. Among those who will benefit are the elderly and children. Those impaired by fatigue, illness, medication, alcohol, or drugs will also benefit. Others may simply not want to drive or be concerned about their ability to do so (DFT 2015).

The individual benefits of automation will depend on how frequently the automated functions are switched on. For many drivers who enjoy manual driving and demonstrating their skills in it, automated driving may not appeal in normal circumstances. For these individuals, the benefits of automated driving will be limited.

There will be increased efficiency of time. People will get to places with greater certainty and more directly, because with full automation there is no need to find parking and to travel from parking to the actual destination.

Automated driving at the higher levels will bring about various benefits to individual mobility. People will likely become less interested in owning a vehicle and instead subscribe to different on-demand services for vehicle or ride sharing. Individual mobility may become more affordable. There may also be an individual preference for procuring mobility as a service and not having to spend time on vehicle purchase, vehicle maintenance, and vehicle insurance. Service providers would presumably offer a variety of vehicles tailored to particular uses (e.g., commuting, family holidays, leisure activities). The cost per kilometer of vehicle use is expected to diminish with increased efficiencies in service provision.

For a public transport user, autonomous driverless vehicles and people movers will likely provide smoother travel and improve possibilities for work and leisure activities during travel. It is also likely that driverless operation will shorten service intervals, thereby reducing both waiting times at stops and travel times. However, travel times may also increase if the vehicles are using the same space as vulnerable road users.

3.2.2 Social Benefits

Automated driving will have major benefits for the transportation system in terms of the primary transportation policy objectives of efficiency, road capacity, road safety, and environment.

3.2.2.1 Use of Travel Time

The social benefits of highly automated driving include the more efficient use of time, in that time spent while driving for work can be used more productively and without the safety risk of distraction. This issue has wider implications for the value of time spent in travel, a topic that is already being investigated by transport economists. There may be reduced willingness among travelers to pay for journey time savings in driving, in that car travel will be less costly because the time can be used productively.

3.2.2.2 *Safety*

The impacts on road safety are expected to increase with higher levels of automation, and full automation should assist in the elimination of serious road crashes, as the main risk factor of human error will be totally excluded. There is significant challenge, however, in being able to deliver interaction with drivers of nonautomated vehicles and with vulnerable road users (pedestrians, cyclists, and riders of two-wheeled motor vehicles). There is also a significant challenge in delivering systems with very low failure rates.

In motorway driving, automated vehicles have the advantages of maintaining full attention at all times (they do not get distracted, fatigued, or impaired by alcohol and drugs) and of faster reaction times than human drivers. Under automation, vehicles will comply with regulations such as static and dynamic speed limits, and both car following and lane keeping will be enhanced because of control that is superior to human performance. Sensor limitations may, however, preclude automatic operation in challenging conditions such as snow.

Safety can be further enhanced by the following technologies:

- V2V communication to deliver cooperative adaptive cruise control and smart platooning, which will help to eliminate shock waves and secondary crashes and could help to eliminate crashes in conditions of poor visibility, such as fog, in which there currently are still significant multivehicle collisions that often result in serious injuries and fatalities;
- Assisted lane changing to overcome failure to detect vehicles in the blind spot, which would be enhanced by cooperative V2V capability to deliver negotiated lane changes; and
- I2V communication to notify vehicles of downstream events beyond the visible horizon.

3.2.2.3 *Efficiency and Capacity*

The effects of automated road transport on efficiency and road capacity are expected to be very high but will depend on the settings for following headway. The smaller the headways used, the higher the road capacity achieved. At low and medium levels of automation, shorter headways could increase crash risk because there could be a requirement for very fast driver reaction in takeover situations.

The effects on efficiency and capacity also depend on the mix of vehicles at various levels of automation and on whether the automated vehicles are equipped with V2X or not. With V2X, automated driving carries much less risk of shock waves and shorter headways can be used. The U.S. DOT (2015) states, perhaps somewhat optimistically, "A fully automated automobile fleet can potentially increase highway capacity five-fold." However, there could be negative effects at lower levels of automation and in interaction with manually driven vehicles. For example, the ability of manually driven vehicles to change lanes (e.g., to overtake slow-moving trucks) could be impeded by automated vehicles driving in platoons with short headways. This scenario implies a potential need to manage the behavior of automated control and provide V2V communication to enable lane changing by nonautomated vehicles. Entrance and exit ramps might have to be managed in a similar manner so that platoons do not block intended maneuvers.

Better lane keeping facilitated by automation would enable the use of narrower lanes for automated vehicles, so that more lanes could be fitted on the same carriageway to increase road capacity. However, this is only achievable with dedicated lanes for automated driving. Interaction with motorcycle riders would have to be considered because filtering between such narrow lanes would not be possible.

Better efficiency will also result if the increased use of vehicle sharing results in a reduction in vehicle miles or kilometers traveled. Such a reduction would lessen congestion and help counteract the effect of population growth on travel demand. There is also a large potential for vehicles to be used more intensively. This point is made by Schoettle and Sivak (2015). They argue that analysis of U.S. travel data indicates that there is considerable potential for vehicle sharing within households because trips do not overlap in location in time. Thus, if vehicles had a return-to-home capability, there would be less need for multiple vehicles within households. They conclude that ownership rates per household could be reduced by 43% and that individual vehicle travel (vehicle kilometers per year) could be increased by 75%.

There is also the potential for operational efficiencies. The use of driverless buses and trams could lower public transport costs and thus act as a counterbalance to the use of low-occupancy door-to-door vehicles. Similarly, the costs of freight transport could be lowered with the advent of long-distance road trains (which should lead to labor efficiencies) and the use of automated pods for local delivery.

3.2.2.4 *Environment*

Vehicles operating under automated control can be expected to save energy and reduce emissions because of smoother driving (i.e., fewer harsh accelerations and decelerations and cruising with less flutter in accelerator control than in manual driving). The maximization of such effects depends on manufacturers' vehicle-control algorithms. Vehicle standards could provide a means to ensure such benefits. There is also the potential to use I2V communication to actively manage energy consumption and emissions, along the lines of the programs for active emissions management already implemented on Dutch motorways. V2V communication is likely to enhance energy savings. Accident reduction would also result in energy savings by reducing network congestion resulting from incidents.

Vehicle sharing would result in substantial energy savings by reducing the energy consumed in manufacture. It could also reduce the land space allocated to parking because, with fewer vehicles being owned, there would be less need for parking in residential areas. However, some of that savings would be canceled out by the movement of empty vehicles around the network to cater to different demand patterns over the day and the week. The need to shuttle empty vehicles around has been noted in regard to urban shared bicycle schemes in cities such as London and Paris.

3.2.3 Service Providers

Overall, as consumption of vehicle travel changes into use of services as opposed to ownership of one or more vehicles, huge economic opportunities are likely to open up for new service providers. Services such as those offered by Uber may be the precursors to that change. Other kinds of new services will likely emerge. Some big players, such as Google, Apple, and Nokia HERE, have already indicated interest in this potential. Software services for connected and automated vehicles, including the provision of infotainment, could constitute a very large market (which may in part explain the interest of Google and Apple). The provision of the software that sits on top of the basic vehicle platform, particularly for driverless vehicles such as urban pods, may be another huge market.

3.3 Costs

The socioeconomic impacts also include costs related to additional investments caused by moving to automation. These costs are presented below on the basis of the stakeholder role in automated driving.

3.3.1 Individuals

When the highest levels of automation are available and used, drivers of nonautomated vehicles, bicyclists, pedestrians, and other travelers outside automated vehicles will be better off if they are aware of the behavior of automated vehicles. Information campaigns and awareness measures may also be required to ensure user acceptance and uptake as well as nonuser acceptance.

3.3.2 Vehicle Owners

The price of a fully automated vehicle could be much higher than that of a manually driven vehicle. However, the costs of vehicle use are likely to diminish with increased sharing of vehicles and higher intensity of use. Indeed, it is likely that there will be less actual ownership and more purchasing of vehicle use as a service. Shared ownership will likely impose some additional costs for managing the use, parking, and maintenance of the vehicle. Another possible option is that automated vehicles could be leased rather than sold to the public, thus allowing the manufacturer to retain control and specify conditions, such as requiring that repairs or servicing be performed only by the manufacturer itself or other parties specified by the manufacturer (DFT 2015). This option would likely increase the costs of having the vehicle. In the long run, if all or most vehicles are fully automated, the urban robot vehicles or pods will likely be much lighter and perhaps also simpler than today's vehicles, which will lower costs of vehicle ownership and use.

3.3.3 Infrastructure Owner–Operators

Automated driving may require considerable investments from the owners and operators of both road infrastructure and information and communications technology infrastructure. Investments for special lanes or roads dedicated to automated driving or manual driving, road markings, traffic signs, roadside solutions, and I2V-V2I infrastructure, which are useful already for Level 3 automation, will increase for higher levels of automation because the coverage of the road network needs to be more comprehensive. In addition some new needs for investments arise:

- Changes in road paving and repaving practices and costs, owing to narrower lanes and stricter lane keeping, and
- Other changes in road infrastructure.

Road paving and repaving practices may face major changes resulting from automated driving. Stricter lane keeping allows narrower lane width and therefore more lanes to be fitted on the same carriageway, which will improve road capacity. Narrower lanes will also mean that vehicles' wheels run over the same parts of the road cross section, which will focus pavement wear on narrow strips along the road, with the result of the formation of wear and deformation ruts on the road. Depending on the percentage of trucks with axles wider than those of automobiles, the ruts may also be wider. These ruts will necessitate shortening of the repaving cycle by perhaps 20%. Otherwise, or in addition, changes in road paving will be needed so that the narrow strips on which the vehicle wheels run will be equipped with material that better tolerates wear. This material with higher-quality aggregate for better wear resistance could be 10% to 15% more expensive to use. Furthermore, paving equipment could face major changes to facilitate paving of virtual rails on the road. In any case, the costs for paving and repaving will be affected (J. Törnqvist, personal communication, Feb. 16, 2015).

Facilitating automated driving may also mean higher asset management standards for operation and maintenance concerning, for instance, road pavement conditions.

Automated vehicles may also make other changes in road infrastructure necessary. For instance, modeling studies have found that, particularly at high flows, roundabouts are more efficient than traffic signals for automated vehicles with V2V communications (Azimi et al. 2013). Therefore, signalized intersections will likely be gradually replaced with roundabouts in the long term. In case of the establishment of urban zones restricted to automated public transport in addition to pedestrians and bicyclists, substantial investments could be needed.

3.3.4 Service Providers

For Automation Levels 4 and 5, the quality of digital maps and traffic information must be at a very high level that will involve high maintenance and operation costs from the relevant service providers.

As with nonautomated vehicles, there is a need for breakdown services to deal with broken down or otherwise stopped vehicles. On the one hand, a higher service level will likely be required for automated vehicles, so costs will increase. On the other hand, I2V communications and accurate vehicle positioning may make the service more efficient.

3.3.5 Automotive Industry

The automotive industry may change drastically, in that fewer vehicles will be in use (which perhaps will reduce income from servicing) but vehicles will be used more intensively. Relationships with service providers may be more important than relationships with individuals. There is a risk that the balance of power may switch to service providers, as has happened to some extent in markets such as mobile phones and television services (Internet protocol television).

3.3.6 Authorities

The liability, security, harmonization, and standardization issues already addressed in the short and medium term will need even more efforts in the long term to deal with full automation. Security issues include, for instance, the use of driverless vehicles to commit crimes and as weapons.

4 Conclusions and Open Questions

The impacts of automated driving are neither obvious nor simple, particularly with regard to fully automated door-to-door services. Nor will those impacts necessarily be favorable in all aspects. To a significant extent, outcomes will depend on how the introduction and roll-out of the new technologies and new forms of vehicles are regulated.

Investments are required from a variety of stakeholders, and, as usual, those carrying the costs will not share the benefits of automated driving to the same degree. The benefits may also accumulate in a quite different place than the costs. These issues need to be solved, as do major institutional and legal issues.

Certainly, there are many issues that should be opened up for public discussion, so that the process of arriving at the necessary political decisions can begin. Before that debate can take place, there needs to be more research that moves beyond pure technology development and human-in-the-loop or human factors studies to a deeper assessment of the wider impacts.

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Abbreviations

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U.S. DOT	U.S. Department of Transportation

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APPENDIX C

Use Case Scenarios

Use Case Scenario 1
Freeway Platooning: Moderately Automated Freeway Operation

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Use Case Scenario 1 considers the operation of privately owned or commercial Level 2 and 3 automated vehicles on freeways[1] or express highways (controlled access) in interactions with other traffic. Vehicles (automobiles, trucks, buses) operate individually or in platoons. Individual operations are dependent on motor vehicle standards. Operation in platoons on particular highways is subject to approval by the road operator and may involve dedicated lanes, temporal restrictions, and minimum vehicle performance requirements. The examples are the Drive Me project (Sweden)[2] and Peloton (United States).[3]

Overall Scenario

The next level of cruise control is common on private and commercial vehicles. Authorities have ruled that this feature be available only on limited-access highways, such as expressways or freeways, and vehicle manufacturers favor this policy as well because it limits their liability exposure.

Platoons of commercial vehicles operate steadily on European and American freeways. Although limited to designated roads, these platoons are impressive sights as they sweep by at up to 130 kilometers per hour (approximately 80 miles per hour) with gaps of 6 meters. Countries and regions restrict speeds in nondedicated lanes, however.

The capacity for freight traffic on the designated roads has increased by 15%. The energy efficiency of participating vehicles has been enhanced by as much as 16% for trailing vehicles and 8% for the lead vehicle, which saves fuel for petrol-powered vehicles and reduces the environmental impact of engine emissions. In the case of electric vehicles, operational energy efficiency also reduces the environmental impact at power generation sites and extends the range of battery- and fuel cell–powered vehicles.

Private passenger vehicles are able to join the commercial vehicle platoons. With the use of vehicle-to-vehicle (V2V) communications, business models have emerged in which consumers can join platoons for a fee. These private vehicles are able to proceed in automatic mode individually on specified freeways.

Safety has been improved from the days before the deployment of platooning. There are dramatically fewer accidents involving heavy vehicles, although an occasional adverse interaction between manually controlled vehicles—especially passenger vehicles—on the same freeway results in a very dramatic and severe accident.

The economic and societal impacts of moderately automated freeway operation are significant. Heavy vehicles are now more competitive than ever, without having become larger, and reduced transportation costs have invigorated Internet commerce by reducing shipping costs. Road transport has a new competitive edge on certain types of delivery as compared with rail. Commercial fleets have followed interoperable standards, and vehicles from different companies collaborate fully on the highways. Consumers can now make the time of their longer commutes and travels productive, and the use of private vehicles for commuting and shorter business trips is increasing because the flexibility and comfort of operating a private vehicle is now more attractive than public transportation for medium-length trips. This change has also affected the design of vehicle interiors and the use of wireless connectivity in the vehicle.

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[1] Note: Around the world, freeways are known by various terms, for example, *Autobahn* (Germany), *autopista* (Spain), *autostrada* (Italy), and *snelweg* (the Netherlands).
[2] See https://www.media.volvocars.com/global/en-gb/media/pressreleases/136182/volvo-car-group-initiates-world-unique-swedish-pilot-project-with-self-driving-cars-on-public-roads.
[3] See http://www.peloton-tech.com/.

Context

This highway platooning scenario is created within the next 2 to 3 years. State highway agencies are attracted to technological means of dealing with increasing truck traffic and related congestion. For modest effort and cost, agencies are able to bring about significant gains in the efficiency of current infrastructure. Agencies need to invest in new signage, roadway markings, and, in some cases, dedicated lanes. Connected vehicle technology (V2V and cellular 3G LTE) according to the national standard is a prerequisite. Public agencies recover their costs through a distance-based charge for platooned operation (over and above the gas tax, which is still in place).

Vehicle-to-everything (V2X) messaging occurs, but no data are retained. All other roadway operations remain the same. Liability for incidents and crashes remains with the driver and the freight operating company. The general public is broadly appreciative of vehicle connectivity and Internet access from vehicles. The provision of access to platooning for private passenger vehicles leads public opinion toward acquiescence with closely spaced truck platoons and special infrastructure provisions for trucks.

Sectoral Perspectives

User Experience (What's in It for the User?)

Commercial drivers are required to obtain additional training and certification to be a lead or following driver in a platoon. For drivers in following vehicles, hours of service rules provide credit for time spent platooning–following. Commercial vehicle platooning results in increased vehicle utilization, and therefore more favorable rates and an increase in the jobs available in this sector. Drivers can multitask while driving on the highway, and time may be spent in other endeavors, such as additional training. Truck driving has therefore become attractive to a new demographic of drivers. Professionalism in truck driving has increased for certain sectors of the motor carrier industry, including large national fleets. However, some elements of the industry are seeing opportunities to deploy less-skilled drivers with minimal training.

Consumers in private vehicles have undergone significant changes in behavior now that travel time on the highway is much more productive. Travelers now choose to drive between spaced destinations instead of using trains or short flights. Internet connectivity allows travelers to communicate and carry out transactions.

Mixed traffic of manually operated vehicles and automated vehicles is a critical issue for safety and public acceptance.

City–Authority (What's in It for the Public Side?)

From the public point of view, the operation of automated vehicles on highways enhances the quality of life, even if the automation is only partial or conditional (Level 2 or 3). In addition to being an assistance tool, autonomous driving cuts fuel consumption and consequently lowers emissions and improves air quality, because the system automatically adapts speed in response to oncoming events.

Impaired mobility and congestion is influenced by the use of these new technologies. The vehicle adapts its speed and time gap at a freeway entrance ramp if another vehicle wants to filter in. Traffic flow in relation to capacity is therefore managed much more efficiently.

From the public standpoint, platooning is being promoted because it improves traffic safety. Some public authorities believe, on the basis of positive experiences, that automated vehicles should be strongly encouraged: in the immediate future no one should be killed or seriously injured.

Autonomous vehicles and a freeway infrastructure adapted to the new technology will provide road users with safer traffic and an improved environment as well as contribute to the creation of a new market, new jobs, and new opportunities. City, regional, and roadway managers therefore designate corridors, routes, roadways, and lanes for use by platooned vehicles. In some cases, new lanes are constructed for platooned vehicles. Public opposition to "truck only" lanes is overcome by the ability of private cars to join and benefit from platoons.

Business (What's in It for the Private Side?)

Freight haulers see a reduction in costs per load per kilometer, and this reduction has positively affected their competitiveness with other modes of freight transport. These cost advantages are a significant competitive advantage between fleets that compels all companies to adopt the technology quickly.

Consumers in their vehicles have time to stay connected, which leads to a tremendous increase in the available daily time slots in which they are connected and available for advertising. These found minutes in the day are in an environment in which consumers' other options are limited, and this time is therefore extremely productive for advertisers. This development leads to increased consumer consumption of entertainment, principally video.

Research

In the near future, the research on automated vehicles operating on the freeway should focus on several areas:

- How can the societal and economic impacts of such automated vehicle technology applied to the motorway context be quantified? Are traffic simulations good enough?
- What would be the requirements of the freeway infrastructure for the operation of platoons?
- What may be the unintended consequences of introducing platoons in freeways together with manually driven vehicles?
- What are the typical traffic situations suitable for platoon operations?
- How should V2V communication protocols be extended to enable dialog and negotiations between involved vehicles before and during platooning?
- Is there a need from the digital infrastructure? What are the data needed?
- Are there legal issues that prevent this operation in the next 2 to 3 years?
- What are the responses and reactions of road users using or interacting with automated vehicles?

Potential Uncertainties, Barriers, and Opportunities

The following issues are raised as thought starters only. The treatment is not intended to be complete or binding for the purposes of the symposium.

Technology

- What is the role of V2X communications, both V2V between vehicles and vehicle to infrastructure (V2I) to the infrastructure and to the cloud? Is V2X essential for platooning?
- What vehicle headways are practical while still retaining efficiency benefits?
- Will it be possible for following commercial vehicles to be driverless?
- What is the practical limit for the length of platoons?
- How will adverse weather affect the availability of automated driving?
- Will these systems be limited to factory installation or will there be aftermarket devices as well?

Legal

- What are the discussion issues and points to be considered with standardization organizations for the definition and extension of communication protocol?
- What are the barriers in national and international law to the operation of automated vehicles on the highway, and what are the changes needed?
- Are there any unique legal considerations for platooning vehicles?

Policy Making and Regulations

- What is the maximum allowed speed for automated vehicles on the highway?
- How will the authorities have to adapt existing regulations, or create new ones, or both, to ensure the full compatibility of these vehicles with the public's expectations regarding safety, legal responsibility, and privacy?
- What is the impact on the equipment of existing and new infrastructure?
- What are the criteria for the design of new infrastructure and relevant equipment?
- Will platooning vehicles be restricted to dedicated lanes?

Business Models

- What business models might emerge for allowing passenger cars to join commercial vehicle platoons?
- How will insurance premiums change with statistics on accident rates?
- What business forces might emerge to encourage and accelerate the deployment and acceptance of automated vehicles?

Human Factors

- What are the unknown human factors issues, such as expectations for the driver to take control on occasion?
- What are the issues with mixed traffic (manual and automated)?

Security

- What applications are required in terms of safety?
- What actions need to be carried out to maintain an updated digital infrastructure without impacts on safety and security? Is standardization needed?
- Are special precautions necessary for platoon-capable vehicles?

Certification, Testing, and Licensing

- Will certification be required of automated commercial vehicles that operate in platoons?
- Will special licensing be required of vehicle drivers to act as platoon lead?

- What maximum speed will be used to test automated vehicles on highways?
- Will automated vehicles be subject to regular inspection and certification?
- Will automated vehicles be limited to maximum speeds different from posted speed limits?

Public Acceptance

- How will consumers react to high-speed platoons of large vehicles?
- Are there some foreseeable unintended consequences of operating automated vehicles and platoons on highways?

Use Case Scenario 2
Automated City Center: Highly Automated Urban Operation

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Use Case Scenario 2 considers vehicle automation for negotiating dense urban traffic as well as parking within a city center. The city center is characterized by high-density employment and residential development, closely spaced signalized and networked intersections, parking structures, and multiple street uses (automobile, truck, transit, bicycle, pedestrian). The examples are two relevant European projects: AdaptIVe[4] and iGAME.[5]

Overall Scenario

The scenario represents a high level of personal vehicle automation [Society of Automotive Engineers (SAE) Levels 3 and 4] that allows the driver to transfer driving tasks to his or her personal vehicle in a networked urban center. The vehicle operates at low to medium speeds with the driver in place.

Before beginning the trip, the driver enters the destination into the vehicle navigation system via a connected app. One of the routes offered is "most automated." As the driver navigates into the urban environment, the driver engages into a car-following mode (similar to SAE Level 2) and oversees the operation. On given sections of the trip (including roads, arteries, and even intersections) in which automation is approved or suitable, the vehicle may offer to engage the Level 3 or 4 automated mode. As the driver transfers the driving task to the vehicle, the vehicle keeps the driver informed on the foreseen time until the next possible manual intervention.

An urban traffic operation system monitors the urban road network for any potential issues and may ask the vehicle to come back to a SAE Level 2 automation mode; that is, the driver is asked to monitor the driving task again but not necessarily with the need to intervene. Without the driver's intervention, the vehicle negotiates the urban street system, optimizing its choice of lanes and speed to avoid stops and reduce fuel consumption until it comes to a road that is not approved or not suitable for Level 3 automation.

The traffic operation cloud communicates messages to the vehicle as well as other street users (transit vehicles, bicyclists, pedestrians) to optimize overall system flow. The system uses communication channels between the vehicle and an urban traffic operation cloud connected to smart traffic signal controllers and other sensors.

If the vehicle is notified about the lack of parking space at its destination or a faster multimodal option, the driver may also be advised during the trip to stop at a designated parking area and continue his trip with another mode of transport.

If the driver does not have designated parking, the vehicle determines available parking before reaching the destination. The vehicle searches the city parking database for parking availability within one-quarter mile (or one-quarter kilometer) of the final destination, and the automated system begins to dynamically route the vehicle to the general location of available spaces at a structure, lot, or on-street location. As the driver arrives at the urban center, the vehicle transmits parking availability and pricing information to the driver. After the driver selects a parking preference, the space is reserved, and the vehicle adjusts its route and automatically drives itself to the parking location. Upon reaching the parking space, the driver exits the vehicle and the vehicle goes into fully automated mode to park itself in its designated space (garage, lot, or on-street).

Context

The first complete example of this scenario could take place within 5 years with strong involvement of a few leading cities. Economic development imperatives lead cities to seek smart city status and generate local pride in the earliest deployment of intelligent systems. In this scenario, the cities targeted exclude megacities in which

[4] See http://www.AdaptIVe-ip.eu.
[5] See http://www.gcdc.net/i-game.

multimodal rail transport is predominant (see Figure 1). Instead, the scenario targets the kind of cities in which the city leaders give preferential treatment to automated vehicles (which are still privately owned) and continue to accommodate conventional vehicles (whose operations in the city center are strongly regulated or priced at a premium). City leaders' intense focus on the avoidance of crashes, injuries, and fatalities drives significant changes in the way city transportation infrastructure is managed. These changes include smarter intersections, smarter interactions with pedestrians and cyclists, smarter modal connections, and smarter parking. V2X connectivity is an important pillar of the city's smart transportation infrastructure.

These significant changes are realized by means of public–private partnerships. The city works with new service providers who price vehicle mobility within the city along with parking as a single service. Above all, the big data generated by vehicle movements and related transactions are used by the city and its partners to orchestrate a completely new level of harmonious traffic movement and safety.

Users enjoy reduced insurance rates in response to lowered crash probabilities. However, traffic incidents and crashes have not been eliminated, and the city and its partners, including original equipment manufacturers (OEMs), bear new liability for these events. Trips within the city are not exclusively by privately owned passenger vehicles; service providers make good use of existing modes of public transport to interface with vehicle travel and parking.

Sectoral Perspectives

City–Authority (What's in It for the Public Side?)

The scenario described may result in better network performance and more efficient vehicle routing, minimizing the traffic circulation and congestion caused by the search for parking (assuming that the trip demand remains the same). The benefits include

- Optimized flow along main corridors of the city,
- Reduced fuel consumption and emissions in urban environment,
- Reduced stops,
- Reduced accidents, and
- Optimized parking supply and revenue generation (for publicly owned parking facilities).

The scenario may encounter some resistance by leaders in the smart city movement. It may lead to an increase in urban vehicle miles traveled, as reaching the city center and finding a place to park may be easy and comfortable. City officials may prefer to favor vehicle-sharing schemes integrated with multimodal travel and

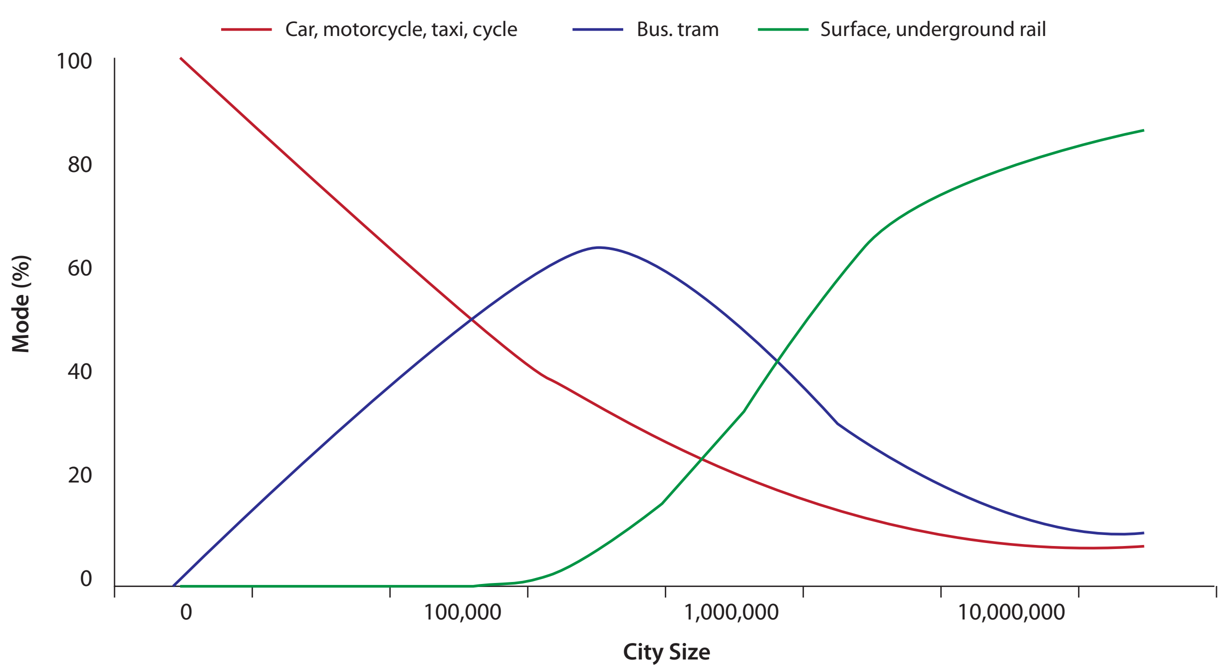

FIGURE 1 Mobility: mode options in European cities of different sizes. (Source: Mike McDonald, University of Southampton, Southampton, United Kingdom.)

keep the parking opportunities for private users entering the city perimeter.

Business (What's in It for the Private Side?)

This scenario opens opportunities for integration of vehicle and infrastructure systems into a seamless and invisible underpinning to the effective movement of people and goods. The operational concept supports the notion of smart cities, a movement that envisions the use of digital technologies to connect transportation with other sectors, including energy, health care, and water and solid waste services, with the aim of furthering economic and environmental objectives.

Navigant Research estimates that by 2023, cumulative global investment in smart city infrastructure will reach $174 billion.[6] The integrated, strategic urban transportation management described in this scenario provides opportunities for private sector involvement in data analytics–system optimization of the urban network, modal integration, payment integration, and parking infrastructure operation.

Perspectives (Time Frame)

The deployment will probably be in steps, starting with specific areas within the urban center.

Lower levels of automation (Level 3) and automation in certain restricted areas (Level 4 parking) will be introduced first. The anticipated time frame is as follows:

- Level 4 parking: 2018 to 2020 and
- Level 3 urban automation: 2025 or later (investments in infrastructure typically require a long time frame).

Research

[To be discussed at the symposium.]

Potential Uncertainties, Barriers, and Opportunities

The following issues are raised as thought starters only. The treatment is not intended to be complete or binding for the purposes of the symposium.

Technology

- What are the technology requirements to advance this use case, both for vehicles and for urban traffic management systems?
- Will data centers that aggregate vehicle and infrastructure data, or traffic management clouds, need to be created?
- What will be necessary in the design and development of automated applications to support this scenario? How do onboard sensors and communication technologies for connected vehicles converge?
- What are the interoperability issues between vehicles and the traffic system?
- What mechanism will define vehicle interaction with other urban travel modes?

Legal

- What are the legal issues, particularly with respect to the liability of the vehicle operator in Level 3 versus Level 4 modes, the vehicle manufacturer–supplier, and the traffic system owner–operator?
- What are the roles and responsibilities of public agencies to provide relevant operations for the vehicles in this scenario? What is the public agency's responsibility for reliable connectivity and accurate information? For roadway certification?

Policy Making and Regulations

- What are the issues for urban network infrastructure investment, especially with respect to the long lead time for capital investment? What about public funding for ongoing operations and maintenance?
- What are the quantifiable benefits that would justify public investment?
- Are there implications for urban mobility planning, including land use impacts?
- Are there professional capacity concerns regarding the public workforce in supporting the urban traffic management system?
- Is there need for enabling legislation for private partnerships and procurement strategies to support this use case?

Business Models

- What are the commercially viable business models that facilitate this particular use case, and how can the various stakeholders enable them?

[6] Navigant Research. *Smart Cities*, 2014. http://www.navigantresearch.com/research/smart-cities.

- Is there a viable business model in which the customer pays more for the features?
- If vehicles can park themselves, what are the impacts on land use or use of space in a parking garage?
- Will time driven with automated features be logged for the purpose of reduced insurance rates?
- Will only low-cost technology be needed for some features? (For example, vehicle dynamics technologies for sharp cornering will not be necessary anymore.)
- What is the best order for introducing automated features? At a first glance, luxury and business cars will have automation. What could be gained by reversing this order, that is, starting with a volume model? In doing so, industry might raise acceptance in a broad level and not through slow democratization.
- How will societal benefits be maximized with mixed fleet operation? To what degree will automated vehicles be prioritized in the operation of the street network or in the assignment of parking?

Human Factors

- What are the human factors challenges with this scenario, particularly with respect to the transition between levels of automation and, potentially, multiple transitions based on road system certification?
- What concerns may arise with a driver making a parking selection while in Level 3 mode?

Security

- What are the security issues and the respective roles of the public and private sectors?
- Which security level will be sufficient for connected vehicles?
- Will an information technology specialist be needed in each repair shop?
- Is identification of the driver before driving needed to ensure proper assignment of driver to responsibility?

Certification, Testing, and Licensing

- What will be required for verification and validation of systems?
- How will road segments be certified?
- Will driver training or selection be needed for rental cars with high automated content?
- What is the impact on training for obtaining a driving license?

Public Acceptance

- What are the consumer acceptance issues?
- What are the public acceptance concerns that may affect political action? How can the public and private sectors influence?
- What happens when no parking is available?
- Is the multimodal alternative acceptable?
- What happens when a driver changes plans?
- Will route and parking space depend on vehicle type, and, if so, what are the acceptance concerns?

Use Case Scenario 3
Urban Chauffeur: Fully Automated Tailored Mobility Service

Natasha Merat, University of Leeds, Leeds, United Kingdom
David Agnew, Continental Automotive NA, Auburn Hills, Michigan, USA

Use Case Scenario 3 considers highly automated vehicles (SAE Level 4) on given urban routes on which a driver is no longer required for vehicle control and operation.[7] The vehicles currently operational in this space use highly accurate mapping and guidance technologies to follow a designated route, which can be a shared urban road or a separate track. The vehicles are not owned by individuals but shared among users in an urban setting.

In a 5- to 10-year time frame, it is foreseen that these vehicles will be used as a complementary feeder service to main public transport networks or in tandem with car- and bike-sharing schemes. These vehicles will be capable of traveling safely on given roads of the cities at a low speed (≤45 kilometers per hour) and may be part of the future of public transport systems that promise to reduce urban congestion and the need for vehicles owned by individual users within cities. The urban chauffer is also useful for areas with low to medium demand and can be summoned on demand by using call points or smartphone technology. With the same technology, the service may provide a single-passenger vehicle or one that can carry up to 12 people.

Today most such systems operate in well-controlled restricted or dedicated environments, such as amusement parks, industrial complexes, and airports. They require a degree of protective infrastructure that limits interaction with other traffic and road users. Examples of vehicles in place include the Personal Rapid Transit at Heathrow

[7] The full SAE description is "the driving mode–specific performance by an automated driving system of all aspects of the dynamic driving task, even if a human driver does not respond appropriately to a request to intervene."

Airport in the United Kingdom and Masdar in the United Arab Emirates, the Park Shuttle Group Rapid Transit system at Rivium in the Netherlands, and the rail-based group rapid transit in Morgantown, West Virginia, USA.

There is now a gentle move toward integrating these vehicles within a more mixed and shared urban space. Examples of projects wishing to realize this concept include the Google pod concept; the CityMobil2 project; the Low-Carbon Urban Transport Zone at Milton Keynes, United Kingdom; and the Food Valley project in Wageningen, Netherlands.

Overall Scenario

Driverless vehicles have been successfully tested and deployed in many controlled environments. They are capable of embracing many potential risks and hazards in detecting obstacles and vulnerable road users (VRUs) as well as other nonautomated vehicles. An advanced version of these vehicles may have the capabilities described in the following scenario.

A user, living within the range of operation of a privately owned service, uses a smartphone app linked to a billing service to call for a vehicle from his or her home. The user identifies location and destination and a desired departure or arrival time; receives route alternatives, including multimodal choices; and picks his or her best choice. A fleet management system selects the best vehicle to dispatch, which may be one that is either already on the route with other users on board or an empty vehicle. The vehicle drives automatically to the user's address, pulls into the driveway, and stops. The user validates the e-ticket and enters the vehicle, which continues its route to the metro station. The vehicle drives into the designated stopping area of the metro station and stops at a safe unloading zone close to the entrance. The user exits the vehicle, and the vehicle moves on to its next user. The multimodal journey continues until the metro station of arrival, where a vehicle drives out from a densely parked area to a dedicated pickup zone. The user jumps into the vehicle, which drives him or her to the final destination.

The fleet vehicles drive along roads that are designated accessible for an SAE Level 4 vehicle, completing all routing, turning, accelerating, and braking as needed automatically. The vehicle is connected to a fleet operator that guarantees the service and to the infrastructure (via V2I technology) to support safe and efficient movement at intersections.

Context

This scenario takes place within the next 10 years as a complement to the rail and metro transportation in a large city. Users from all parts of society are united in their expectation of mobility on demand—anytime, anywhere. Mobility services are available to all ages and demographics, regardless of whether the person currently drives or not.

Public agencies at the city, county, regional, and state levels grant access to licensed mobility service providers, subject to a usage fee for the infrastructure. Vehicle technologies are sufficiently advanced that wide access can be granted without prohibitive infrastructure costs. Public agencies welcome such mobility services because more citizens enjoy more mobility at a lower cost. At the same time, legacy problems of crashes, congestion, and pollution are being systematically eliminated.

Automated vehicle technology has evolved to the point that it is greatly trusted by the general public.[8] This high degree of reliability and trust has resulted in the transport industry's investing in a new level of variety and adaptability in vehicle designs that can be tailored for many specific driverless applications. Such applications address the movement of passengers as well as the delivery of goods. These new vehicles are intended to be shared and offer new levels of efficiency and affordability. Vehicles are owned, operated, and offered to consumers through a new business model of mobility as a service (MaaS). Driverless vehicles are still a minority and need to interact safely with conventional human-driven vehicles as well as with privately owned vehicles with varying levels of automated capability. Wherever this mix of traffic may represent risks, segregation of tracks may be planned, similar to bike paths on large roundabouts.

Extensive data are collected by the mobility services company and used to optimize services. Certain data are provided to public agencies under infrastructure access agreements in order to efficiently manage the infrastructure and monitor the public impact of driverless vehicle operations on traffic behavior.

In comparison with conventional human-controlled vehicle highway operations, driverless vehicles are very safe, and the contiguous operation of conventional vehicles has also become safer. Nevertheless, relatively infrequent but complex system crashes occur. Therefore, comprehensive risk assessment and management are required and are provided by third parties that enter into agreements with mobility service providers, public agencies, and OEMs. These agreements are supported by quality systems that include universal performance standards for vehicles, infrastructure, and the related roadside technology.

[8] The studies made in the field in the Cybermove (2001–2004), CityMobil (2006–2011), and CityNetMobil (2008–2011) projects show that once the public has actually tried a fully automated vehicle, it trusts the technology; that is, evolution of automated vehicle technology beyond today's state of the art is not required before the public will trust the technology.

Sectoral Perspectives

User Experience (What's in It for the User?)

This service is thought to be particularly useful for those who do not wish to drive or cannot drive. Acting as what is effectively a public transport system, these vehicles provide the user with the ability to engage in other tasks during the commute to and from home to destination with minimal waiting time between modes. The potential use of these vehicles is very attractive for people with impairments and disabilities as well as for older citizens who no longer wish to drive or are unable to drive and for young people without a license or the resources to own a vehicle. However, further usability and ergonomic requirements may be required to accommodate these populations.

The level of service linked to the travel time and reliable multimodal transfers for such service in a mixed space needs to satisfy user expectations.

City–Authority (What's in It for the Public Side?)

With a dramatic reduction in parked private vehicles, public spaces have become free spaces. Transport in urban settings has become much safer as the number of crashes, especially with VRUs, has been reduced. However, there is a need to ensure that safe communication and interaction with VRUs are considered during vehicle and sensor development. Indeed, the safe behavior of the vehicles might induce a different (less rule-abiding) behavior on the VRU side, which would make it more complex for such vehicles to navigate.

These vehicles dramatically reduce the use of private transport in an urban environment and thereby reduce congestion and transport-related emissions. This concept may also increase the adoption of public transport (demand driven).

Business (What's in It for the Private Side?)

The business model in this scenario shifts from ownership to usership with MaaS in mind. Some vehicle manufacturers have become directly engaged in providing urban mobility services.

New service providers have entered the market, own the vehicles, and engage with customers. Current services such as Uber provide, as a model, a part of the service described above but fail to integrate the multimodal dimension. The role of diffused or shared ownership is a new paradigm in which many business opportunities may open up the competition to new players. The result may be a lower volume of vehicles on urban roads but increased usage, which will keep mobility and vehicle miles traveled to the same level and therefore lead to a younger and often renewed vehicle fleet.

Private companies specifically benefit by engaging consumers in their products in a space that no longer requires the driver's attention to the road. Advertising will therefore play a big part in this form of transport, as drivers become passengers able to surf the net, watch movies, and interact with their smart devices.

Research

There is a desire on the part of both urban authorities and businesses to deploy and test the feasibility of such systems. The EU CityMobil2 demonstration projects focus on the use of these vehicles in six European cities and the United Kingdom. In the United States, Google has announced its intention to deploy its next phase of such vehicles for on-road evaluation. These activities indicate the need to begin answering many of the new questions and challenges associated with highly automated vehicles. Some research areas for these vehicles include

- Evaluation of the effectiveness of the sensors and perception systems to perform the specific mission,
- Overall system reliability and safety and the trade-off with the availability of the system,
- The potential for accelerating implementation or optimizing performance via modifications to the existing road and infrastructure,
- Exploration of unintended interactions with users and other stakeholders,
- Enhanced methods of verification that provide confidence in system performance and system safety in timely and economically tenable ways,
- Use of V2X communication to further optimize performance, and
- Identification of the limits of interaction with other road users and road types (isolated versus go anywhere).

Potential Uncertainties, Barriers, and Opportunities

The following issues are raised as thought-starters only. The treatment is not intended to be complete or binding for the purposes of the symposium.

Technology

- How effective and sensitive are the sensors implemented on these vehicles?

- How do the vehicles interact and communicate with other road users and other (nonautomated) vehicles?
- Can vehicle behavior become more acceptable, so that automated vehicles do not simply stop in the presence of all obstacles but negotiate the road network intelligently?
- How do weather conditions affect the operation of these vehicles?

Legal

- As no drivers exist in these vehicles, will the fleet operator agree to be liable for malfunction?
- What needs to be done to prepare stakeholders for this shift of risks and responsibilities?
- Can the overall risk reduction be measured? What is the proportion of the shift of risk between stakeholders?
- In view of national and international law, what are the different nations doing to enable the operation of fully automated vehicles?
- What are the roles and responsibilities of the public authority in the operation of fully automated vehicles?

Policy Making and Regulations

- What is the policy for allowing such vehicles in shared space?
- What are the acceptable safe speed and risk levels in different infrastructures?
- What is the best proportion of these smart vehicles compared with other means of public transportation such as buses, taxis, shared vehicles, and shared bikes?

Business Models

- What is the value to cities of implementing these vehicles?
- What business forces might emerge to encourage and accelerate the deployment and acceptance of automated vehicles?

Human Factors

- What are the most effective ways for automated vehicles and VRUs or other road users to interact?
- What is the best way to interact with the user so that he feels comfortable sharing the vehicle, depending on demand between origin and destination?
- How should the system interact with users in cases of vehicle breakdown or incident? Would it be sufficient to dispatch a new vehicle, as is done for taxis today?

Security

- What security measures are needed for the operation of such vehicles in isolated areas or at night? Do these measures annihilate the benefits of automation or require the presence of an operator?
- Are there security issues or data protection issues related to origin–destination information? Do these issues differ from those of existing services such as Uber?
- What is the appropriate response to incidents, and how rapid is the response time from the operator or emergency services?

Certification, Testing, and Licensing

- Will different certificates and testing procedures be required for different infrastructures and layouts in cities?
- Will certification be based on vehicle speed appropriate for the area?

Public Acceptance

- What are the consumers' needs for such vehicles?
- Which consumers will use these systems?
- Will the vehicle provide safe, fast, and efficient door-to-door service?
- Is the service affordable for those who need it most?

APPENDIX D

Final Program

TOWARDS ROAD TRANSPORT AUTOMATION: OPPORTUNITIES IN PUBLIC–PRIVATE COLLABORATION

EU-U.S. Transportation Research Symposium 3

Organized by
U.S. Department of Transportation
European Commission
Transportation Research Board

April 14–15, 2015
National Academy of Sciences Building
Washington, D.C.

Tuesday, April 14, 2015

8:30 a.m. **Welcome and Introductions**
Peter Sweatman, University of Michigan Transportation Research Institute (UMTRI), *Chair*
Kevin Womack, U.S. Department of Transportation
Alessandro Damiani, European Commission
Neil Pedersen, Transportation Research Board

9:00 a.m. **Keynote Presentation**
Chris Urmson, Google

White Paper Presentation: Road Transport Automation as a Public–Private Enterprise
Richard Bishop, Bishop Consulting
Steven E. Shladover, University of California, Berkeley

White Paper Presentation: Road Transport Automation as a Societal Change Agent
Oliver Carsten, University of Leeds
Risto Kulmala, Finnish Transport Agency

Setting the Stage for the Symposium
Maxime Flament, ERTICO-ITS Europe

10:30 a.m. Morning Break

11:00 a.m. **Use Case Scenario 1**
Freeway Platooning: Moderately Automated Freeway Operation
Peter Sweatman, UMTRI
Maxime Flament, ERTICO-ITS Europe

11:20 a.m.	**Working Group Discussions on Use Case 1**
12:30 p.m.	Lunch
1:30 p.m.	**Summary and Discussions of Use Case Scenario 1** Peter Sweatman, UMTRI Maxime Flament, ERTICO-ITS Europe
2:15 p.m.	**Use Case Scenario 2** **Automated City Center: Highly Automated Urban Operation** Ginger Goodin, Texas A&M Transportation Institute Aria Etemad, Volkswagen
2:35 p.m.	Afternoon Break
3:05 p.m.	**Working Group Discussions on Use Case 2**
4:15 p.m.	**Summary and Discussions of Use Case Scenario 2** Peter Sweatman, UMTRI Maxime Flament, ERTICO-ITS Europe
5:00 p.m.	Adjourn

WEDNESDAY, APRIL 15, 2015

9:00 a.m.	**Use Case Scenario 3** **Urban Chauffeur: Fully Automated Tailored Mobility Service** Natasha Merat, University of Leeds David Agnew, Continental Automotive NA
9:20 a.m.	**Working Group Discussions on Use Case 3**
10:30 a.m.	Morning Break
11:00 a.m.	**Summary and Discussions of Use Case Scenario 3** Peter Sweatman, UMTRI Maxime Flament, ERTICO-ITS Europe
11:45 a.m.	Lunch
12:45 p.m.	**General Conclusion and Discussion** Peter Sweatman, UMTRI Maxime Flament, ERTICO-ITS Europe
2:30 p.m.	**Closing Session** Peter Sweatman, UMTRI Maxime Flament, ERTICO-ITS Europe Kevin Womack, U.S. Department of Transportation Alessandro Damiani, European Commission Neil Pedersen, Transportation Research Board
3:00 p.m.	**Adjourn**

APPENDIX E

Symposium Attendees

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