CAVita *giving life to transformational technology in transportation*

National Cooperative Highway Research Program

CEO Leadership Forum 2017

White Paper – World Congress Version

Connected and Automated Technologies and Transportation Infrastructure Readiness

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DISCLAIMER

Glossary of Terms

AAMVA: American Association of Motor Vehicle Administrators

AASHTO: American Association of State Highway and Transportation Officials

ADS: Automated Driving System

ASCT: Adaptive Signal Control Technologies

AV: Automated Vehicle
A vehicle that has one or several of a very wide range of automated driving features and replaces certain aspects of driver perception and control.

Autonomous Vehicle
An *automated vehicle* that relies entirely on its own onboard sensors for situation awareness in the roadway, and therefore for exercising vehicle control functions.

BSM: Basic Safety Message

CAMP: Collision Avoidance Metrics Partners, LLC

CV: Connected Vehicle
A vehicle enabled for standardized communication between vehicles or with the roadside, to enable driver assistance applications for the purposes of safety, traffic efficiency, reduced fuel consumption or reduced emissions.

DSRC: Dedicated Short Range Communication

FHWA: Federal Highway Administration

FMCSA: Federal Motor Carrier Safety Administration

HAV: Highly automated vehicle, of SAE Level 3 or above

HOS: Hours of Service rules (applicable to truck drivers)

LiDAR: Light Detection and Ranging

NCSL: National Conference of State Legislators

NLC: National League of Cities

NOCoE: National Operations Center of Excellence

NPRM: Notice of Proposed Rulemaking

OBD: On-board diagnostics

OBU: On-board unit

Platoon: Comprising two or more freight trucks enabled for V2V communication as well as automated longitudinal (and perhaps lateral) control functions.

RSU: Road-side Unit

SPAT: Signal Phase and Timing

TSM&O: Transportation systems management and operations

V2I: Vehicle-to-Infrastructure aspect of CV

V2V: Vehicle-to-Vehicle aspect of CV

V2X: Includes V2V and V2I, and vehicle communication with road users such as motorcyclists, cyclists and pedestrians.

Executive Summary

The ITS World Congress 2017 (Sunday, October 29th to Thursday, November 2nd) sessions, exhibits, technical tours, and demonstrations offer unique perspectives and updates in the field of ITS, transformational technology, policy and deployment. In addition to the World Congress experience, NCHRP Leadership Forum participants will participate in a workshop to discuss their learnings from the week and the emerging developments in the field.

Among many changes being experienced by public sector transportation agencies, and notably by state DOTs, the development of connected and automated vehicles (CAVs) is highly transformational. Further, the deployment of CAV technology on our streets and highways will occur in the presence of additional technological and industrial changes that add to opportunities and uncertainties in planning, managing and operating the transportation infrastructure.

This White Paper aims to provide a backgrounder on CAV developments over the past two to three years, along with selected topics that are likely to influence the deployment of CAVs, namely: smart cities, cybersecurity and privacy, big data and shared mobility (SM). The paper also considers potential ramifications for today's policy makers, planners and regulators, as well as certain issues that may become more significant for state DOTs as technology moves forward. The considerations within the White Paper provide a framework for participation in the 2017 ITS World Congress, and the paper includes guidance on relevant activities in technical and policy sessions, exhibits and demonstrations. Finally, the paper raises discussion points for an event's-end workshop for the 2017 NCHRP Leadership Forum in association with AASHTO.

In order to assist the Leadership Forum participants' preparation, we suggest approaching CAVs as a central topic with closely-related technologies: big data and cybersecurity. We also recommend attention to deployment opportunities and issues for CAVs, and consideration of the strong influence of smart city programs, automated vehicle (AV) applications in the trucking industry, and the highly synergistic development of the SM industry.

Relevant themes for the Leadership Forum participants include:

- Deployment of vehicle-to-infrastructure (V2I) technologies, including the role of connected vehicle (CV) technology in supporting the deployment of AV;
- Avoiding increased safety risks during the "AV transition period" – when AVs mix with conventional vehicles, and AV driver/operator roles are still evolving;
- CAV data collection, analytics, access and security; leadership roles for state and local agencies;

- The trucking industry as an early adopter of CAVs; opportunities in freight corridors with increasing truck traffic;
- Technical and policy assistance to cities for CAV programs;
- The development of the shared mobility industry, the role of smart city programs and acceleration of AV deployment;
- The business case and models for public agency engagement in CAVs; and
- Challenges and synergies for the energy sector. (*1*)

These themes will be well represented at ITS World Congress 2017. More information on the topics discussed in the White Paper will be forthcoming as ITS World Congress 2017 approaches. The program for the Leadership Forum Workshop is being developed in consultation with the Leadership Forum, NCHRP and AASHTO. The workshop program will include feedback on all key themes and will provide added focus on selected topics and issues. Results from the workshop will be captured within the knowledge center of the National Operations Center of Excellence for easy access.

1. Introduction

The purpose of National Cooperative Highway Research Program (NCHRP) Leadership Forum activity at ITS World Congress (WC) Montreal 2017 is for the chief executive officers (CEOs) of selected state Departments of Transportation (DOTs) to explore transportation technology. The ITS World Congress sessions, exhibits, and demonstrations offer unique perspectives and updates in the field of Intelligent Transportation Systems (ITS) and its deployment. In addition to the Congress experience, Leadership Forum participants will join a workshop to discuss developments.

A similar activity took place in 2014, at the ITS World Congress in Detroit, Michigan (*2*). Hosted by the American Association of State Highway Transportation Officials (AASHTO), the participating CEOs focused on the potential implications of deployment of connected vehicles (CVs) within their states. It was recognized that there were many technical and policy issues associated with CV deployment.

Meaningful actions that the CEOs identified included their need to establish a vision and set goals for CV, secure financial support, engage their Departments of Motor Vehicles (DMVs), participate in the V2I Deployment Coalition (V2I DC), define a data strategy, look to the freight industry as early adopters, and undertake staff development. Going into the ITS World Congress Montreal in 2017, these actions are well advanced and remain relevant. However, the pace of transportation technology has advanced exponentially and automated vehicles (AVs) have a central place in 2017.

Among many changes being experienced by public sector transportation agencies, and notably by state DOTs, the development of connected and automated vehicles (CAVs) is highly transformational. Some observers consider CAVs to be a tipping point in transportation, of a magnitude only seen at intervals of many decades. Further, the deployment of CAV technology on our streets and highways will occur in the presence of additional technological and industrial changes that add to uncertainties in planning, managing and operating the transportation infrastructure.

This White Paper aims to provide a backgrounder on CAV developments over the past two to three years, along with selected topics that are likely to influence the deployment of CAVs, namely: smart cities, cybersecurity and privacy, big data and shared mobility (SM). The paper also considers potential ramifications for today's policy makers, planners and regulators, as well as certain issues that may become more significant for state DOTs as technology moves forward.

The paper builds upon the continuing CV and AV research and deployment programs of the U.S. Department of Transportation (U.S. DOT) as well as the body of literature on CAV technologies that has been instrumental in underpinning this rapidly evolving field. Of particular note are recent publications by the Transportation Research Board's (TRB's) National Cooperative Highway Research Program (NCHRP), including its

“Connected/Automated Vehicle Research Roadmap for AASHTO” (project 20-24(98)) (*3*), “Impacts of Connected Vehicles and Automated Vehicles on State and Local Transportation Agencies” (project 20-102) (*4*), and “Challenges to CV and AV Applications in Truck Freight Operations” (project 20-102(03)) (*5*), among others. Also of note is TRB’s transportation research circular E-C208, “Transformational Technologies in Transportation” (*6*).

The considerations within this White Paper provide a framework for participation in the 2017 ITS World Congress, and the paper includes guidance on relevant activities in technical and policy sessions, exhibits and demonstrations. Finally, the paper raises discussion points for an event’s-end workshop for the 2017 NCHRP Leadership Forum.

ITS World Congresses are renowned for providing rapid-cadence updates from technical and policy perspectives. Each World Congress is an important annual, structured, public-private-academic dialog for advancing the deployment of beneficial technologies. The policy challenges posed by far-reaching technical advances receive timely consideration, with worldwide participation by experts and decision makers.

The 2017 NCHRP Leadership Forum, created in association with AASHTO, occurs at a time of rapidly accelerating R&D in CAV and related topics. The subject matter is no longer “brand new”, nor speculative: engagement in these topics will be highly rewarding to members of the Leadership Forum and their organizations. The Leadership Forum represents a valuable opportunity to consider aspects of the “fully evolved future” of mobility as well as immediate steps and challenges with CAV deployment and related technologies.

2. State of the Art for Connected and Automated Vehicles (CAVs)

The quantity and maturity of CAV platforms and activities has experienced exponential growth in recent years. This section discusses the current status of these technologies, the industries that develop them, and the various drivers, scenarios, policies, and competitive forces that led to the current status and are poised to influence their development and deployment pathways.

At the same time, key national stakeholders including TRB, NCHRP, AASHTO, the Institute of Transportation Engineers (ITE), and ITS America have been extremely active in developing technical and institutional support for deployment actions made possible by the co-operative R&D programs of the U.S. Department of Transportation (U.S. DOT).

We provide a description of what is meant by "CAV", how it has advanced in the recent past, and the relationship between its component parts: connected vehicles (CVs) and automated vehicles (AVs). In this and the following section of the paper, we partly draw on and update a TRB publication prepared by the authors in early 2016 *(6)*.

2.1 Connected and Automated Vehicle Technologies

Given the frequent use of terms involving connected and automated vehicles, we first establish definitions, and descriptions of the main technologies and their functions. The field includes connected vehicles (CVs) and automated vehicles (AVs).

CV includes vehicle-to-vehicle communication (V2V), vehicle-to-infrastructure communication (V2I), and "V2X", broadly representing communication between vehicles, infrastructure and other road users (such as pedestrians and cyclists). V2I involves deployment of sensing and connectivity in the infrastructure and potentially interfaces with advanced traffic applications utilizing Intelligent Transportation Systems (ITS).

AV includes automated and "autonomous" vehicles covering a very broad range of automated function and environment. AVs are equipped with Automated Driving Systems (ADSs) which are designed and evaluated for safe operation on public roads and which satisfy safe driving regulations. Highly-automated vehicles (HAVs) include those closest to driverless capabilities and are of particular significance in enabling disruptive change in the mobility of people and freight. Currently, CV and AV are pursuing parallel technological and policy paths, their relationship is evolving, and there is no formal relationship at the national level. The major national stakeholders, including U.S. DOT and state agencies, are active in both CV and AV and are encouraging a supportive relationship between the technologies.

2.1.1 Overview and Definitions

"CV" generally refers to both connecting vehicles and infrastructure, and to connection among all ground vehicle players: cars, freight trucks, and buses – and potentially motorcycles, bicycles, and pedestrians. Connected technologies include licensed wireless regimes such as dedicated short-range communication (DSRC), the newer cellular technologies (together these regimes are often referred to as V2X), and potentially telematics, satellite, and Internet.

The "connected" part of "connected and automated" generally refers to a V2X-enabled capability that creates machine awareness of the trajectories of equipped vehicles in the immediate vicinity. This machine awareness applies to vehicles as well as specific features of the infrastructure, such as intersections and curves. Such machine awareness may be used to identify safety risks, but also to condense or smooth traffic flow. These applications of the technology require warnings or notifications for drivers, in order for the driver to make the required vehicle corrections.

The **components of connected vehicle systems** are well-defined, and include the following elements:

- The on-board unit (OBU) fitted to the vehicle, for broadcasting and receiving defined message sets (principally the Basic Safety Message (BSM));
- The road-side unit (RSU) fitted to roadside furniture at intersections and other locations, for broadcasting and receiving defined message sets (principally signal phase and timing (SPAT) and the BSM);
- The V2X applications that process messages and devise driver warnings; certain applications may require vehicle data via connection to the vehicle's on-board diagnostics (OBD) port; vehicles contain both V2V and V2I (or I2V) applications;
- The interface between the OBU and driver in the vehicle;
- The interface between the RSU and signal controller; and
- The data backhaul from RSUs to a central location.

The "automated" part of "connected and automated" refers to various levels of replacement of human perception and control, and is applicable to cars, freight trucks, and buses. However, the definition also includes new configurations of these base vehicle units, such as platoons. Automated vehicle features have to some extent evolved from a class of advanced driver assist systems (ADAS).

The terms "automated" and "autonomous" are often used interchangeably. However, autonomous usually means a vehicle that relies entirely on its own onboard sensors for situation awareness in the roadway, and therefore for exercising vehicle control functions. Automated vehicles may cover a very wide range of automated driving features, often falling well short of fully automated capabilities.

The Society of Automotive Engineers (SAE) Standard J3016 (Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems) (*7*) is widely referenced and identifies **six driving automation levels**[1], comprising:

- Level 0 – No Automation: The full-time performance by the human driver of all aspects of the dynamic driving task, even when enhanced by warning or intervention systems;
- Level 1 – Driver Assistance: The driving mode-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the human driver performs all remaining aspects of the dynamic driving task;
- Level 2 – Partial Automation: The driving mode-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the human driver performs all remaining aspects of the dynamic driving task;
- Level 3 – Conditional Automation: The 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;
- Level 4 – High Automation: 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;
- Level 5 – Full Automation: The 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.

In September 2016, the U.S. DOT adopted this standard into the National Highway Traffic Safety Administration (NHTSA) Federal Automated Vehicles Policy (FAVP) for safe testing and deployment of automated vehicles,[2] thereby aligning and formalizing a commonly used shorthand for quickly and concisely categorizing automated vehicle technologies and capabilities. NHTSA recently released an updated and revised version of this guidance entitled Automated Driving Systems 2.0: A Vision for Safety.

2.1.2 Recent Technological Developments

Connected Vehicles

While the vehicular side of CV is ready for production vehicles (as evidenced by GM's deployment in selected 2017 models), considerable R&D effort has been devoted recently to V2I technology and applications. Work led by the Federal Highway Administration (FHWA) and the Collision Avoidance Metrics Partners, LLC (CAMP) has developed an increased range of V2I applications. Work by FHWA has developed the connections between RSUs and traffic controllers, and ITS/controller companies have

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[1] http://standards.sae.org/j3016_201401/
[2] https://www.sae.org/news/3544/

developed SPAT products. R&D has been carried out to develop “pseudo BSMs” that broadcast BSMs on behalf of unequipped vehicles present in an intersection.

A new generation CV security system has been developed by U.S. DOT. Work continues on alternative wireless regimes to DSRC, capable of the message integrity and low latency required for V2X safety applications. Continuing deployment of heavy truck platooning applications demonstrates how CV can support AV functionality. In passenger vehicles, OBD-II devices are now commonly available that use 4G mobile connections to establish in-vehicle Wi-Fi hotspots for passengers. Such units have the potential to facilitate broader V2X functionality.

Automated Vehicles

With many of the basic challenges associated with enabling Level 1 and 2 driving solved, technology developers focused attention on developing the ability for AVs to recognize and safely respond to unconventional and unanticipated road conditions, paving the way for Level 4 and 5 automated driving. These efforts have largely been oriented around **developing artificial intelligence (AI) software** for vehicular control. In 2016 and 2017, developers achieved meaningful advancements within two particular categories of AI best positioned to solve the complex challenges associated with higher levels of automated driving: machine learning and, more importantly, deep learning.

Machine learning programs are fed very large amounts of data – from datasets, the Internet, and, in the case of CAVs, from an array of vehicular sensors and networks, among other sources – and use the data to, over time, learn from experience and improve their performance to achieve a programmed objective without being explicitly programmed to do so.

Deep learning programs similarly learn from experience, but do so through more layers than machine learning or other shallow algorithms. At each layer, deep learning algorithms transform the data via neural networks that emulate the process humans follow to examine solutions in parallel and in convoluted ways to inform a course of action. Deep learning is particularly helpful for vehicular settings, for it can better handle the unpredictability of complex urban and suburban circumstances, while synthesizing with human-controlled vehicles.

The importance developers place on advancing machine and deep learning has created fierce competition for quality software and talented computer scientists and engineers. The last year and a half has seen **large corporate transactions** driven primarily by this competition, as well as stiff competition for developers. Examples include:

- The staffing and ramping up of activities at the $1B Toyota Research Institute Inc. (TRI)[3], an R&D enterprise established with a $1B investment by Toyota in November 2015, focused on artificial intelligence and robotics.[4]

[3] http://www.tri.global/

- General Motors' March 2016 $581M acquisition of Cruise Automation,[5] a company that at the time was only three years old and was focused on converting certain types of cars into AVs, but was known for having developed promising AV control software. GM has since allocated responsibility for GM's AV development to Cruise.
- Uber's $680M acquisition of Otto, a company that builds kits to enable automated control in trucks, but more importantly was founded and operated by veterans of Google's self-driving car program and has created sophisticated AI software and hardware for AVs.
- Ford's early 2017 $1B acquisition of a majority stake in Argo AI, a recently-formed company led by former Google and Uber engineers that developed AI software for AV control, and that now is focused on developing the software platform for Ford's self-driving cars.

Beyond software, 2016 and 2017 saw the continued **advancement of vehicular sensors**, with a primary drive to reduce the size and cost of historically bulky and expensive units. Many view Light Detection and Ranging (LiDAR) units, which are able to accurately gauge a vehicle's surroundings in many complex situations, as essential to enabling higher levels of autonomy.

Better LiDAR is a core part of Waymo's plan to make self-driving cars a mass market and a profitable proposition. The company has developed three different sensors that look for objects at different ranges. While early units built by Velodyne, ubiquitous in prototype vehicles, cost upwards of $75K each, Waymo has been able to reduce the cost of its LiDAR units by more than 90 percent by improving the components' design.[6]

Waymo is not alone in working to advance LiDAR. In 2016, Ford and Baidu, the Chinese search company investing in self-driving cars, jointly invested $150 million in Velodyne. The company is building a new "megafactory" in San Jose that's scheduled to start producing LiDAR in 2018.[7] Startup Luminar has raised $36 million in seed-stage funding, and claims to have new LiDAR sensor that uses chips, lasers and receivers designed by the company to see further and in more detail than those on the market.[8]

As a result of these and other investments, costs are expected to decrease further. Solid-state designs, which steer lasers electronically rather than via spinning mirrors, have the potential to reduce costs simply because they don't have moving parts. Velodyne is one of several companies working on solid-state designs, and in December 2016 announced that its latest design could deliver a subsystem cost of under $50 U.S.

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[4] http://newsroom.toyota.co.jp/en/detail/10171645/
[5] http://media.gm.com/media/us/en/gm/news.detail.html/content/Pages/news/us/en/2016/mar/0311-cruise.html
[6] https://medium.com/waymo/introducing-waymos-suite-of-custom-built-self-driving-hardware-c47d1714563
[7] https://www.technologyreview.com/s/603885/autonomous-cars-lidar-sensors/
[8] https://www.technologyreview.com/s/604136/college-dropout-says-hes-cracked-self-driving-cars-most-crucial-component/

when sold in high-volume manufacturing scale.[9] Startup Quanergy, which has $135 million in funding, says it will start producing solid-state LiDAR sensors at a factory in Massachusetts this year and sell them for $250.[10] Continental and Valeo are working on similar technology of their own and say it will come to market in two or three years.[11]

2.1.3 Emerging Relationship Between CV and AV

The terms “connected” and “automated” are often used together from the perspective that they are among the most exciting, or far-reaching, technologies currently being talked about in transportation. But how and when do connected and automated come together? It is commonly believed that CV is an enabler of AV, and that incorporating CV with AV is critical to realizing societal benefits such as reduced congestion, improved mobility, and reduced fuel consumption. However, there are some companies that are pursuing AV without a strong CV component. There is much to play out here before final approaches crystalize: first in terms of what specific benefit is provided when automated vehicles of various stripes become connected; and second in terms of the rate at which connectivity becomes available, and where it is available within the network.

If we view CV as a supportive technology for highly automated vehicle (HAV) deployment, it is possible to come up with a number of technical scenarios whereby CV and AV converge. Examples of scenarios for deploying CV infrastructure to specifically support AVs include[12]:

- CV serves as an additional, or redundant, sensor for the HAV in locating other vehicles and predicting their motion;
- CV provides HAVs with information that is difficult to detect autonomously; for example, the layout of roadworks, or location of pedestrians in intersections;
- CV provides information to the HAV, specific to HAV crash types; for example, the HAV advises following vehicles when it is stopping at signalized intersections and stop signs; and
- CV provides information to the HAV on-board system concerning the current operating environment; the HAV then decides whether automated operation is desirable or not.

Continued advancement and updates in the infrastructure space are crucial to preparing roads for automated vehicles. While AVs may be tested in off-roadway facilities, most companies engaged in AV development place high value on miles logged on public roadways. If that infrastructure is able to broadcast key roadway data to AVs, rather

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[9] http://www.businesswire.com/news/home/20161213005517/en/Velodyne-LiDAR-Announces-Breakthrough-Design-Miniaturized-Low-Cost
[10] https://www.technologyreview.com/s/602503/fist-sized-laser-scanner-to-make-autonomous-cars-less-ugly/
[11] https://www.technologyreview.com/s/603885/autonomous-cars-lidar-sensors/
[12] http://www.caee.utexas.edu/prof/kockelman/public_html/TRB17EconomicEffectsofAVs.pdf

than each AV having to create its own "situation awareness", the deployment of HAVs will occur a lot faster, and more safely.

2.2 Scenarios for Deployment

2.2.1 Groups Driving CAV Development and Adoption

The advent of CAVs brings a wider range of players than we have seen previously in transportation. There are **eight broad categories of stakeholders** involved in the development and adoption of CAVs:[13]

I. Policy development. Largely carried out by government at the federal, state, and local levels. Industry, academia, and research play a supporting and advisory role. Policy development applies to motor vehicles, infrastructure equipment, and telecommunications.
II. Vehicles. Designed, manufactured, and distributed by original equipment manufacturers and suppliers in several tiers. Certain equipment is also designed, manufactured, and distributed in the aftermarket.
III. Infrastructure. The nation's system of streets, roadway structures, and associated equipment and roadside furniture. Designed, constructed, maintained, and operated by state and local agencies, with federal government assistance. Equipment such as traffic management systems is designed, manufactured, and supplied by traffic equipment suppliers.
IV. Personal technology ("tech"). Manufacturers and providers of personal devices and services to consumers, and to other business sectors such as vehicle manufacturers. Includes inroads by "tech" companies into vehicle development: tech cars that are automated, connected, and electrified.
V. Communications, computation, and big data. The underlying telecommunications technology, the carriers, and the retail providers of phone and data services. Included are cellular and wireless regimes such as Wi-Fi, as well as the Internet and computation services on the vehicle and in the cloud. Also included are big data services creating information and applications in and around the high velocity and high-volume data streams being created by CVs and infrastructure.
VI. Insurance, standards, and security. Motor vehicle insurers are active in data-intensive insurance products and may develop new insurance concepts for automated vehicles. This refers to national and international standards bodies covering automotive and communications and to the security approaches adopted by vehicle and equipment manufacturers.
VII. Mobility services. This is a relatively new segment reaching critical mass through a diverse range of consumer-oriented services. Included are the more-established services such as fleet services, telematics, tolling, and fare payment. Also included are smart parking, carsharing, ridesharing, ridesourcing, and trip

[13] http://onlinepubs.trb.org/onlinepubs/circulars/ec208.pdf

planning. This includes the on demand, networked ride services constituting shared mobility (SM) (e.g. Uber, Lyft).

VIII. Convening, deployment, and evaluation. The more traditional aspects of convening are carried out by industry associations and professional bodies. Universities and local agencies also organize efforts for deployment and economic development. Such consortia usually carry out evaluation activities.

The first deployments of driverless vehicles are likely to be in **certain scenarios** where:

- They're able to solve immediate challenges;
- The technological complexity is sufficiently manageable to eliminate safety concerns; and
- Returns on investment and other economic parameters are favorable.

Prime **examples of these categories** include:

- Long-haul trucking: Platooning and other higher levels of automated truck technologies can provide a clear and near-term return on investment. Testing done by the National Renewable Energy Laboratory (NREL) demonstrated fuel savings up to 5.3 percent in the lead truck while the trailing truck saved up to 9.7 percent.[14] Automated trucks are estimated to save about $1.67 per mile compared to standard trucks.[15] Given hours of service (HOS) constraints on human drivers, automated trucks could allow more hours of operation. Finally, highway operations may prove technically easier for automated vehicles to manage than complex urban settings.
- Closed communities and campuses: Retirement communities and universities may serve as deployment zones for automated vehicles. In these scenarios, the demand for mobility solutions is more predictable. Additionally, conditions are suited to simple, small, low-speed automated vehicles and shuttles.
- Shared mobility. With many predicting a future for the automobile that is automated, shared, and perhaps electrified, automakers could quickly find their products and brands commoditized as travelers develop less affinity for brand ownership and more for economical, timely, on demand transport that offers popular in-vehicle services and amenities while traveling. The potential cost reductions with driverless, on demand vehicles are compelling.

2.2.2 Key Connected and Automated Vehicle Applications and Deployments

In recent years, vehicle and technology manufacturers, the U.S. government, and universities (and other third parties) have contributed to CAV testing and demonstration programs. While some initiatives have targeted both CV and AV, many are oriented to one or the other.

[14] https://www.nrel.gov/transportation/fleettest-platooning.html
[15] https://insights.samsung.com/2017/04/17/telematics-lays-the-foundation-for-autonomous-trucking/

Connected Vehicle Deployment

The U.S. DOT has overseen a tightly integrated program of CV research, bench testing, test beds, field trials, standards development, and model deployment.[16] Prominent CAV test sites already in operation, or getting underway, tend to have a specific, local university partner and an explicit component dedicated to private industry participation and collaboration. These **CAV test sites** include:

- Arizona Connected Vehicle Program identified how new technology applications could enhance traffic signal operations, incident management and traveler information. It led to what became the Maricopa County Department of Transportation (MCDOT) SMARTDrive[SM] Program, which prevents emergency vehicles from colliding with one another at signalized intersections. MCDOT constructed a test bed in Anthem to test the program's vehicle prioritization technology in 2011. It was one of the first seven test beds in the country. The technology developed by Arizona's Connected Vehicle Program contributed to the development of the U.S. DOT's Multi-Modal Intelligent Traffic Signal System (MMITSS). The program has now expanded its testing to include new applications such as a pedestrian traffic signal crosswalk application, transit priority application and a trucking priority application.[17]
- Ann Arbor Connected Vehicle Test Environment (formerly Safety Pilot) has been operated by the University of Michigan (U-M) since 2012 with the world's largest contingent of DSRC-connected cars, trucks and buses. The USDOT-funded Safety Pilot served as a catalyst for further related developments in Southeast Michigan, including the U-M's Mobility Transformation Center (MTC), Mcity (launched in 2015), and the American Center for Mobility (ACM).
- Chattanooga Connected Vehicle Pilot Development (Tennessee) is premised on a 2015 plan with the University of Tennessee to bring connected vehicle technology infrastructure into Chattanooga for safer and more efficient transportation operation.[18]
- Colorado Department of Transportation's RoadX is a $20 million initiative to deliver innovative solutions for crash-free, injury-free, delay-free, and technologically transformed travel in Colorado. The effort builds upon the state's Managed Motorways project along the I-25 South Corridor and the Connected Vehicle Pilot Project along the I-70 Mountain Corridor.[19] In October 2016, Panasonic announced that it is partnering with RoadX to build a connected transportation system to share real-time data across vehicles and infrastructure to improve driver safety and roadway efficiency.[20]
- Ohio's Smart Mobility Corridor will be comprised of advanced highway technology along a 35-mile stretch of US 33 northwest of Columbus. The

[16] http://onlinepubs.trb.org/onlinepubs/circulars/ec208.pdf
[17] https://www.maricopa.gov/640/Connected-Vehicles-Program
[18] http://www.chattanoogan.com/2015/3/20/296454/City-Seeking-To-Be-Test-Site-For.aspx
[19] https://www.codot.gov/business/engineeringapplications/copy_of_assets/tech_magazine_11212016.pdf
[20] http://shop.panasonic.com/about-us-latest-news-press-releases/10262016-intelligent-transport.html

corridor will be equipped by the Ohio DOT with high-capacity fiber optic cable to instantaneously link researchers and traffic monitors with data from embedded and wireless sensors along the roadway beginning in mid-2017. Sensors along the road will send data to researchers at the Transportation Research Center at East Liberty and The Ohio State University's Center for Automotive Research. The Smart Mobility Corridor is a key component of the state's new Smart Mobility Initiative.[21]

- Michigan Department of Transportation (MDOT) has been extremely active in CAV deployment and thought leadership in transformational technology. The MDOT Smart Corridors Initiative, announced at the 2014 ITS World Congress, is actively deploying over 300 miles of connected vehicle infrastructure and V2I applications by 2018. The MDOT Smart Corridors will allow for CAV testing and operations, supporting partnerships developed with multiple automotive manufacturers and suppliers. MDOTs CAV support includes fostering industry relationships and education by holding quarterly connected and automated vehicle working group meetings, which brings together government, industry and academia to share and discuss critical topics that can influence and accelerate the innovation and growth of the CAV industry. The State of Michigan has passed a number of public acts in support of automated vehicle research, develop and operations, including the legal operation of driverless vehicles and mobility services, truck platooning, and manufacturer owned automated vehicle fleets. Another highlight of the AV public acts is the establishment of a Michigan Council on Future Mobility. The Council is comprised of industry experts with crosscutting experience including liability, insurance, infrastructure and automotive technologies, with the mission of informing the State of Michigan legislature on the current and future impact of laws and regulations on CAV and mobility technologies within the state. Michigan continues to support CAV research, development, testing and operations, and future initiatives, projects and goals will be announced at the 2017 ITS World Congress in Montreal, Quebec.
- New York City DOT Pilot will be comprised of approximately 5,800 cabs, 1,250 MTA buses, 400 commercial fleet delivery trucks, and 500 city vehicles to evaluate CV technologies and applications in tightly spaced intersections typical in a dense urban transportation system.[22]
- Pennsylvania is home to the newly designated U.S. DOT Proving Ground comprised of Penn State's Larson Transportation Institute and the City of Pittsburgh's urban core. Testing will occur on Penn State's closed test track, Interstate 99, and on public roadways in the City of Pittsburgh and Borough of State College. Both Penn State and the City of Pittsburgh are working closely with the Pennsylvania Department of Transportation (PennDOT). This activity builds upon PennDOT CV deployments[23] and a nearly $11 million Advanced

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[21] https://www.dot.state.oh.us/news/Pages/SmartMobilityCorridor.aspx
[22] https://www.its.dot.gov/pilots/pilots_nycdot.htm
[23] http://www.itspennsylvania.com/wp-content/uploads/2015/05/ITSA-App-Connected-Automated-Section.pdf

Transportation and Congestion Management Technologies Deployment (ATCMTD) grant to, among other things, deploy smart traffic signal technology.[24]

- Tampa-Hillsborough Expressway Authority Pilot will employ DSRC to enable V2X transmissions among approximately 1,500 cars, 10 buses, 10 trolleys, 500 pedestrians with smartphone applications, and approximately 40 roadside units along the Selmon Reversible Express Lanes (REL) to relieve congestion, reduce collisions, and prevent wrong way entry.[25]
- Utah passed a bill in 2015 that authorizes the DOT to conduct a connected vehicle technology testing program.[26] The state has seen testing on I-80 by CAV truck technology provider Peloton.
- Wyoming DOT pilot will focus on the needs of commercial vehicle operators by using a variety of V2X technologies along Interstate 80 to support a flexible range of services from advisories including roadside alerts, parking notifications and dynamic travel guidance.[27]

Automated Vehicle Testing and Deployment

Several **AV test facilities** have been established and operated in recent years, including:

- UC Berkeley's Partners for Advanced Transportation Technology (PATH) has pioneered automated vehicle platooning and continues to contribute to the safe transition to highly-automated vehicles, and the deployment of heavy truck platooning. A recent initiative of note is Berkeley DeepDrive, an industry consortium developing advanced computer vision and machine learning. DeepDrive involves collaboration with 18 industrial partners, including Original Equipment Manufacturers (OEMs), Tier 1 suppliers, tech companies, communications, IT, and consumer electonics.
- GoMentum Station in Concord, California was announced in October 2014 and currently is the largest secure testing ground for CAVs in the country. AV testing takes place on the facility's roadways, and CV testing takes place by using the facility's smart (V2I) infrastructure, including traffic lights. Participants include Honda, EasyMile, and Otto.
- The Texas A&M University System (TAMUS) is creating a large off-roadway test facility for CAV and smart infrastructure at its 3,000-acre RELLIS facility in Bryan, Texas. Companies are forming consortia to carry out CAV-related R&D in collaboration with the Texas Transportation Institute (TTI). RELLIS is of sufficient scale and built environment for companies to locate large R&D efforts on-site.
- The University of Michigan's Mcity is a 32-acre facility in Ann Arbor, Michigan with diverse roadways, roadside features and infrastructure is a closed, controlled environment that allows researchers to safely test emerging concepts

[24] https://www.transportation.gov/Briefing-Room/Advanced-Technology-Transportation-Projects
[25] https://www.its.dot.gov/pilots/pilots_thea.htm
[26] https://le.utah.gov/~2015/bills/static/HB0373.html
[27] https://www.its.dot.gov/pilots/pilots_wydot.htm

in connected and automated vehicles.[28] The facility includes 13 signalized intersections and incorporates urban, suburban and highway settings, and was opened in July 2015. The MTC consortium brought together more than 70 companies involved in research and deployment programs in and around Mcity. These companies include OEMs, Tier 1 suppliers, ITS, tech companies, communications, IT, insurance, and mobility services.

- The American Center for Mobility (ACM) was created by the Michigan Economic Development Corporation (MEDC), MDOT and the University of Michigan, utilizing the former GM transmissions facility at Willow Run. The construction of a 300-acre multi-environment AV test facility, with attached freeway and interchange sections, is underway. A comprehensive range of test environments and situations for object and event detection are being provided for safety validation of ADSs.
- The Transportation Research Center (TRC) is a long-standing 4,500-acre test facility in central Ohio, with added capabilities for CAV testing. TRC is owned and operated by Honda and the Ohio State University, and has NHTSA as a long-term resident user. US Route 33, connecting TRC with Marysville, is being equipped for V2I testing, providing a link to the Columbus Smart City deployments in CAV.
- Virginia Automated Corridors feature more than 70 miles of interstates and arterials roadway supported by academia, the state's DOT, and private industry that establish an environment and significant research support to create, test, and deploy CAV systems.[29]
- Virginia Smart Road is a 2.2-mile, controlled-access test track research facility managed by the Virginia Tech Transportation Institute (VTTI) and owned and maintained by the Virginia Department of Transportation (VDOT).[30] VTTI recently launched the Automated Mobility Partnership (AMP), bringing together industry partners in a major effort to define operating environments for highly-automated vehicles and provide advanced tools for evaluation and analytics. Extensions to the Smart Road provide structured environments for CAV testing.

Vehicle and technology manufacturers have received considerable attention for their activities, given that most are highly-publicized and on public roadways. In some cases, these deployments allow for public passengers. Key **AV applications and deployments by manufacturers** include:

- Fiat Chrysler (and Waymo) are testing a fleet of 100 Chrysler Pacifica minivans outfitted with Waymo's AV hardware and software package in Mountain View, CA and Phoenix, AZ. In April 2017, Waymo ordered 500 more minivans in order to accommodate what it hopes will be hundreds of riders in Arizona.

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[28] http://energy.umich.edu/research/partner-programs/mcity
[29] http://www.vtti.vt.edu/featured/?p=260
[30] http://www.vtti.vt.edu/facilities/virginia-smart-road.html

- Ford is testing a fleet of Fusion Hybrid Autonomous Development Vehicles in Detroit, MI, San Francisco, CA and Scottsdale, AZ. Ford's acquisition of Pittsburgh-based Argo AI in early 2017 and the expansion of its workforce lead many to speculate that the automaker will establish a substantive testing program in the city.
- General Motors is testing a fleet of more than 50 highly automated Chevrolet Bolts in Detroit, MI, San Francisco, CA, and Scottsdale, AZ. The company states that, in partnership with the ridehailing company Lyft, in which GM invested $500 million in 2016, it will also begin testing "thousands" of automated Chevrolet Bolts in 2018.[31]
- Peloton has, as of August 2016, undergone 15,000 miles of highway testing of its system that allows pairs of trucks to "platoon" in Utah, Nevada, Michigan, Ohio, Florida and California.[32]
- Uber is operating a fleet of automated Ford Fusions in Pittsburgh, PA, California, and Arizona. The Arizona tests were established in 2016 when Uber encountered testing permit issues in California. The company subsequently re-established its San Francisco program in January 2017.
- Waymo maintains a fleet of 23 Lexus SUV test vehicles in addition to the aforementioned Chrysler minivans, as well as prototype HAVs that altogether have carried out over two million miles of on-road testing since 2009,[33] first in Mountain View, CA, and subsequently in Austin, TX, Phoenix, AZ, and Kirkland, WA.

In January 2017, the U.S. DOT took steps to facilitate AV testing when it selected and designated **10 Automated Vehicle Proving Ground test sites** to "encourage testing and information sharing around automated vehicle technologies."[34] (*8*) These 10 locations form a "Community of Practice" that will "foster innovations that can safely transform personal and commercial mobility, expand capacity, and open new doors to disadvantaged people and communities." Proving Ground designees are:

1. City of Pittsburgh and the Thomas D. Larson Pennsylvania Transportation Institute (Pennsylvania)
2. Texas AV Proving Grounds Partnership (Texas) – including the A&M System's RELLIS Campus
3. U.S. Army Aberdeen Test Center (Maryland)
4. American Center for Mobility (ACM) at Willow Run (Michigan)
5. Contra Costa Transportation Authority (CCTA) & GoMentum Station (California)
6. San Diego Association of Governments (SANDAG) (California)
7. Iowa City Area Development Group (Iowa)
8. University of Wisconsin-Madison (Wisconsin)

[31] http://www.reuters.com/article/us-gm-autonomous-exclusive-idUSKBN15W283
[32] https://www.trucks.com/2016/08/28/truck-platooning-technology-advances/
[33] https://waymo.com/ontheroad/
[34] https://www.transportation.gov/briefing-room/dot1717

9. Central Florida Automated Vehicle Partners (Florida) – including the SunTrax test facility[35]
10. North Carolina Turnpike Authority (North Carolina)

The U.S. DOT received more than 60 applications from sites wishing to be designated, and was able to secure broad commitments to cooperate, including "share[ing] best practices for the safe conduct of testing and operations as they are developed, enabling the participants and the general public to learn at a faster rate and accelerating the pace of safe deployment."

2.2.3 Geography of U.S. Deployments and Consortia

As illustrated by Fig 1 & 2, manufacturer, government, academic, and other prominent testing efforts are located in various regions throughout the country, and are thus exposed to a variety of geographic environments, roadway scenarios, weather conditions, and stakeholder groupings.

[35] https://floridapolytechnic.org/news-item/fdot-and-partnership-florida-poly-develop-suntrax/

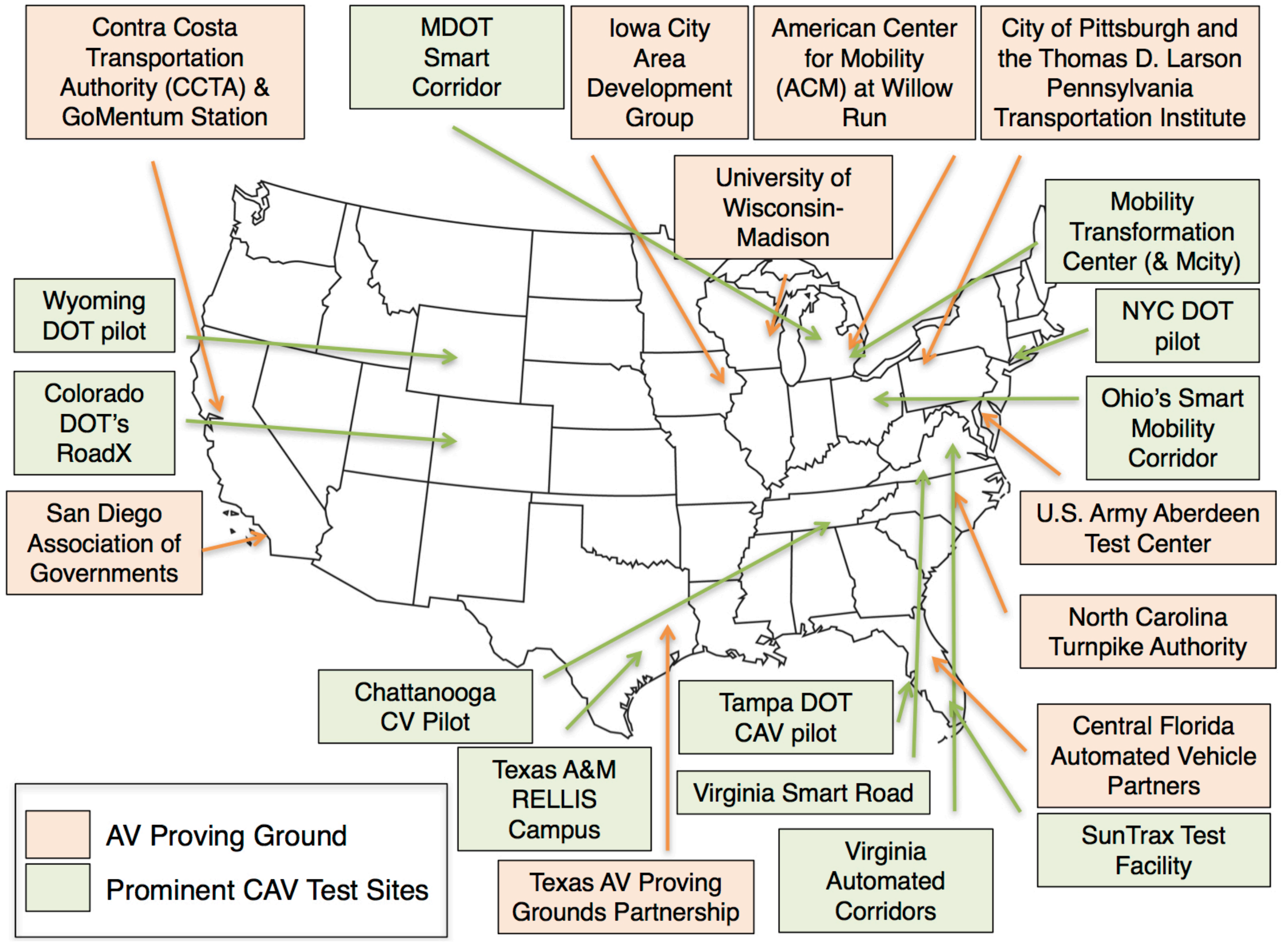

Figure 1. U.S. CAV Consortia Locations

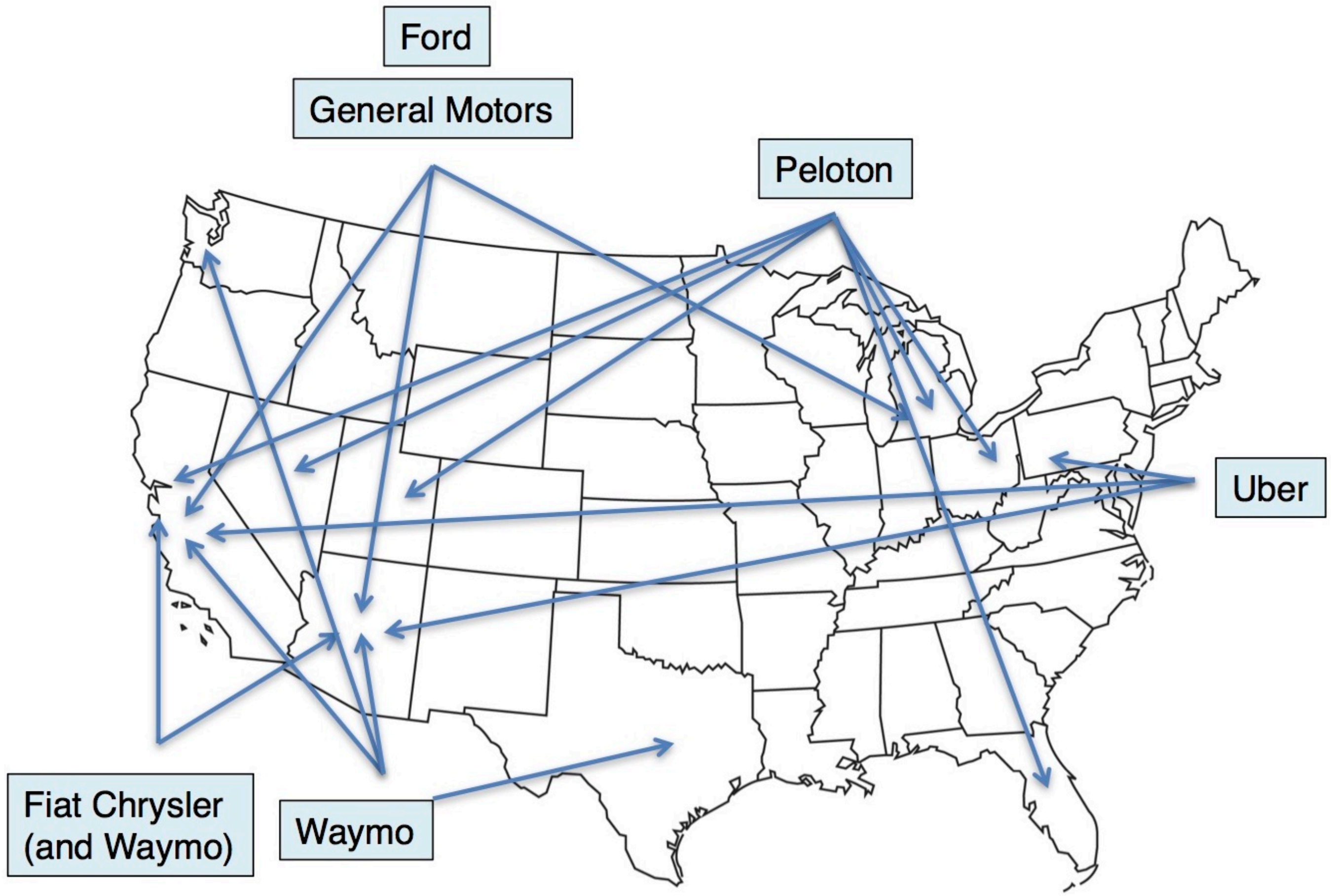

Figure 2. U.S. AV Company Deployment Examples

2.3 Connected and Automated Vehicle Policy Activities

Federal policy actions build upon a substantial body of research conducted by the U.S. DOT, including the programs of the National Highway Traffic Safety Administration (NHTSA), FHWA, the ITS Joint Program Office (JPO), The Federal Motor Carrier Safety Administration (FMCSA), the Volpe Center and the Federal Transit Administration (FTA).

However, CAV policies may originate at any level of government: federal, state or local. Generally speaking, policy initiatives tend to lag behind technological developments. This is especially true in the case of AVs. Nevertheless, we have seen some significant policy actions at the federal and state levels during 2016. This section contains some of the recent highlights.

2.3.1 Actions of the Federal Government in the Introduction of CAVs

U.S. DOT CAV activities include sponsored research funded by NHTSA, FHWA, and the ITS JPO. These activities have focused on automated vehicle technology development and evaluation, policy assessment, and impact evaluation, among others. A **sampling of sponsored research topics** includes:[36]

- Safety standards – identifying where there may be challenges to certifying a range of AV concepts;
- Liability and insurance – synthesizing how AVs potentially impact current liability and insurance models; summarizing possible risk management or policy strategies;
- Legislation – reviewing existing vehicle safety legislation and pending state/local CAV legislation;
- Cooperative Adaptive Cruise Control (CACC) – looking at the ways to overcome the technical, institutional, and market barriers to deployment of this technology, which aims to increase traffic throughput by safely permitting shorter following distances between vehicles;
- Truck platooning – evaluating performance, technology, and commercial viability of truck-based CACC and Driver Assistive Truck Platooning applications;
- Enabling technologies – providing guidance with respect to the underlying enabling technologies common across automated and connected vehicles;
- Driver acceptance – examining critical human factors issues such as workload, situational awareness, and distraction for automation applications; and
- Best practices – developing a guide for jurisdictions in regulating AVs and driver testing.

In early 2016, NHTSA and the Insurance Institute for Highway Safety (IIHS) announced a commitment by 20 automakers to make **automatic emergency braking** (AEB) a

[36] https://ops.fhwa.dot.gov/regulationpolicy/avpolicyactivities/

standard feature on virtually all new cars no later than Sept 1, 2022 (*9*).[37] AEB systems use on-vehicle sensors such as radar, cameras or lasers to detect an imminent crash, warn the driver and apply the brakes if the driver does not take sufficient action quickly enough.[38] The agreement, which is not binding, is estimated to make AEB standard on new cars three years faster than could be achieved through the formal rule-making process.

In the fall of 2016, the U.S. DOT released its "**Federal Automated Vehicles Policy**" (*10*) that envisaged far-reaching principles and guidelines for the safety evaluation of HAVs. The policy package was composed of four sections:[39]

- <u>15 Point Safety Assessment</u> –The Vehicle Performance Guidance for Automated Vehicles for manufacturers, developers and other organizations included a 15 point "Safety Assessment" for the safe design, development, testing and deployment of automated vehicles.
- <u>Model State Policy</u> – This section presented a clear distinction between federal and state responsibilities for regulation of highly automated vehicles, and suggested recommended policy areas for states to consider with a goal of generating a consistent national framework for the testing and deployment of highly automated vehicles.
- <u>NHTSA's Current Regulatory Tools</u> – This discussion outlined NHTSA's current regulatory tools that could be used to ensure the safe development of new technologies, such as interpreting current rules to allow for greater flexibility in design and providing limited exemptions to allow for testing of nontraditional vehicle designs in a timelier fashion.
- <u>Modern Regulatory Tools</u> – This discussion identified new regulatory tools and statutory authorities that policymakers may consider in the future to aid the safe and efficient deployment of new lifesaving technologies.

*We note that a revised set of NHTSA guidelines was released very recently, in September 2017. Entitled "**Automated Driving Systems 2.0: A Vision for Safety**" (11), this document focuses on refining the first two sections of the draft guidelines. These are now titled ADS Safety Elements (including the voluntary safety self-assessment) and Technical Assistance to States. The latter section is particularly relevant to state agencies, and includes best practices for state highway safety officials. Altogether, the new Voluntary Guidance:*[40]

- *Focuses on SAE International Levels of Automation 3-5 – Automated Driving Systems (ADSs) – Conditional, High, and Full Automation);*

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[37] https://www.nhtsa.gov/press-releases/us-dot-and-iihs-announce-historic-commitment-20-automakers-make-automatic-emergency
[38] Ibid.
[39] https://www.transportation.gov/briefing-room/us-dot-issues-federal-policy-safe-testing-and-deployment-automated-vehicles
[40] https://www.nhtsa.gov/press-releases/us-dot-releases-new-automated-driving-systems-guidance

- *Clarifies the guidance process and ensures that entities do not need to wait to test or deploy their ADSs;*
- *Revises design elements of the safety self-assessment;*
- *Aligns Federal Guidance with the latest developments and industry terminology; and*
- *Clarifies Federal and State roles going forward.*

In late 2016, NHTSA and the U.S. DOT published the notice of proposed rulemaking (NPRM) for what is expected to become Federal Motor Vehicle Safety Standard (FMVSS) 150 (*12*), which seeks to **mandate vehicle-to-vehicle (V2V) communications** for new light vehicles and to **standardize the message and format of V2V transmissions**."[41] As drafted, the standard would require vehicle manufacturers to install dedicated short-range communication (DSRC) radios in new vehicles starting around 2023, and to transmit Basic Safety Messages (BSM).

A wide variety of comment was received on the NPRM. At the time of writing, issues including security of DSRC/V2V and alternatives to DSRC are being discussed. OEMs have expressed a range of views. Meanwhile, V2I would remain voluntary but is the subject of significant deployment support efforts by the U.S. DOT, AASHTO, Institute of Transportation Engineers (ITE), ITS America (ITSA) and the V2I industry.

Given the direct connection between CAV technologies and vehicular safety, NHTSA, with its primary responsibility of writing and enforcing Federal Motor Vehicle Safety Standards, plays a crucial role in the introduction of CAVs. Specifically, NHTSA has been involved in defining levels of automation, including the decision to align the government's standards and measurement protocols with SAE standard J3016 in late 2016, thereby determining levels of vehicular automation and standards. NHTSA also has a direct role in defining vehicle and driver roles, as is illustrated by the J3016 definitions, and potential scenarios and use cases. NHTSA's work on **Federal Motor Vehicle Safety Standards** can have direct and indirect effects on the introduction of CAVs, depending on whether standards explicitly or implicitly refer to CAV technologies. These standards state that federal responsibilities include:[42]

- Setting safety standards for new motor vehicles and motor vehicle equipment;
- Enforcing compliance with the safety standards;
- Investigating and managing the recall and remedy of non-compliances and safety-related motor vehicle defects on a nationwide basis;
- Communicating with and educating the public about motor vehicle safety issues; and
- When necessary, issuing guidance to achieve national safety goals.

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[41] https://www.federalregister.gov/documents/2017/01/12/2016-31059/federal-motor-vehicle-safety-standards-v2v-communications

[42] https://www.transportation.gov/sites/dot.gov/files/docs/AV%20Fact%20Sheet%20-%20Model%20State%20Policy.pdf

2.3.2 Actions of National Stakeholders

The **National Operations Center of Excellence (NOCoE)** is a partnership of AASHTO, ITE, and ITSA that also receives support from the FHWA. The NOCoE serves the transportation systems management and operations (TSM&O) community by offering an array of technical services such as peer exchange workshops and webinars, ongoing assessments of best practices in the field, and on-call assistance.[43] It has two primary components: The Operations Technical Services Program, and a web portal that contains case studies, resources, links to information, discussion forums, and a calendar of TSM&O-related events.

The goal of the NOCoE is to provide convenient access to key knowledge resources and the opportunity to discuss topics related to transportation systems management and operations. Included in these key knowledge resources are publications and other tools to help organize CAV stakeholders and share knowledge on CAV technologies and policies. By way of example, an April 2017 FHWA study looked at how CAVs can be incorporated into an integrated corridor management (ICM) approach.[44]

An important national stakeholder action is the **Vehicle to Infrastructure Deployment Coalition (V2I DC)**, where the U.S. DOT joined with AASHTO, the ITE, and ITS America to create a single point of reference for stakeholders to meet and discuss V2I deployment issues. The V2I DC facilitates cooperation between the infrastructure owners and operators (state, county, and local level transportation agencies), the automobile industry OEMs, aftermarket manufacturers and other stakeholders required to deploy, operate, and maintain V2I applications nationwide. The V2I DC's initial goals are to assist the deployment of V2I technologies:[45]

1. At intersections where the majority of crashes and/or congestion occur;
2. To support end of queue warnings in locations with high rates of rear-end collisions;
3. For work zone management; and
4. For curve warning systems.

The V2I DC operates five technical working groups (TWGs): Deployment Initiatives; Deployment Research; Infrastructure Operator, OEM, and Supplier Partnerships; Deployment Guidance; and Deployment Standards.

More recently, the **AASHTO SPAT Challenge** is working to mobilize state and local public sector infrastructure owners and operators to achieve deployment of DSRC infrastructure with SPAT, MAP, and RTCM broadcasts in at least one corridor or network (approximately 20 signalized intersections). The goal is a SPAT Corridor in

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[43] http://www.transportationops.org/overview-nocoe-and-its-programs
[44] http://www.transportationops.org/publications/leveraging-promise-connected-and-autonomous-vehicles-improve-integrated-corridor
[45] http://www.transportationops.org/V2I/V2I-overview

each of the 50 states by January 2020. Ideal SPAT Challenge corridors are envisioned to have:[46]

- Signalized intersection scope of approximately 20 signals;
- Modern controllers with in-cabinet equipment to support the interface with a DSRC radio (the "roadside unit" or "RSU");
- Backhaul communications with sufficient bandwidth from the corridor either from each signal or from a master; and
- The ability to broadcast MAP/GID (Geographic Intersection Description) data.

To facilitate participation, AASHTO and others provide support and facilitate coordination among agencies so they can learn from each other and develop and utilize best practices. The SPAT Challenge website actively posts and updates resources, such as DSRC licensing information, implementation guidance, and corridor selection, for its active and prospective participants. At the time of writing, 17 agencies were identified as pursuing the SPAT Challenge, which includes not only those who have indicated their pursuit on the website, but also informal commitments and those with active DSRC SPAT broadcasts.[47]

2.3.3 Actions of States and Local Agencies in the Introduction of CAVs

The **American Association of Motor Vehicle Administrators** (AAMVA) has been active in promulgating AV knowledge. Various activities include:[48]

- Establishing an AV Information Sharing Working Group in December 2013;
- Developing an AV Information Library on its website to store information on AVs;
- Developing an analysis of current AV state laws; and
- Identifying key program areas such as operator training, testing and licensing, vehicle registration and title, data privacy and security concerns, consumer safety and other areas of concern to the Departments of Motor Vehicles (DMVs) and law enforcement that will be impacted by AVs.

In February 2015, AAMVA launched its Autonomous Vehicle Best Practices Working Group with the purpose of working with the AAMVA jurisdictions, law enforcement, federal agencies and other stakeholders to gather, organize and share information with the AAMVA community related to the development, design, testing, use and regulation of AVs and other emerging vehicle technologies. Based on the group's research, a best practices guide will be developed to assist member jurisdictions in regulating AVs and testing the drivers who operate them.[49]

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[46] http://www.transportationops.org/sites/transops/files/SPaT%20challenge%20Folio%20imposed.pdf
[47] http://transops.s3.amazonaws.com/uploaded_files/AASHTO%20CAV%20-%20April%2018%20webinar%20ver2.pdf
[48] http://www.aamva.org/WorkArea/DownloadAsset.aspx?id=6297
[49] http://www.aamva.org/Autonomous-Vehicle-Best-Practices-Working-Group/

AASHTO's Subcommittee on Transportation Systems Management and Operations' technical working group 5 is active in creating, aggregating and disseminating state-level CAV actions and information. For example, it hosted a webinar in February 2017 on the V2V NPRM, which is discussed in 2.3.1. It also issued the previously-mentioned nationwide challenge to deploy DSRC infrastructure with SPAT broadcast in at least one corridor in each of the 50 states by January 2020, produced a "Connected/Automated Vehicle Research Roadmap for AASHTO"[50], and regularly updates its website with key information and developments on state-level CAV activities.[51]

The **Connected Vehicle Pooled Fund Study** was a multiphase program created by a group of state and local transportation agencies and the FHWA to facilitate the development, field demonstration, and deployment of connected vehicle infrastructure applications.[52] Participating agencies include California DOT, Delaware DOT, Federal Highway Administration (FHWA), Florida DOT, Georgia DOT, Maricopa County in Arizona, Maryland DOT, Michigan DOT, Minnesota DOT, New Jersey DOT, New York DOT, Ohio DOT, Pennsylvania DOT, Tennessee DOT, Texas DOT, Transport Canada, Utah DOT, Washington DOT, and Wisconsin DOT with the Virginia DOT as lead agency and the University of Virginia Center for Transportation Studies as technical leadership provider.[53]

Section 2 of **NHTSA's** newly-released **Automated Driving Systems (ADS) Policy** (*11*) (see 2.3.1) prescribes "Best Practices for Legislatures Regarding Automated Driving Systems".[54] These best practices state that NHTSA is responsible for regulating motor vehicles and motor vehicle equipment – strongly encouraging states to allow DOT alone to regulate the safety design and performance aspects of ADS technology – and that states are responsible for regulating the human driver and most other aspects of motor vehicle operation. Specifically, the best practices set forth states' responsibilities as:[55]

- Licensing human drivers and registering motor vehicles in their jurisdictions;
- Enacting and enforcing traffic laws and regulations;
- Conducting safety inspections, where states choose to do so; and
- Regulating motor vehicle insurance and liability.

The policy provides additional guidance by specifying "Best Practices For Legislatures" as:[56]

- Providing a technology-neutral environment;
- Providing licensing and registration procedures;

[50] http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP20-24(98)_RoadmapTopics_Final.pdf
[51] http://stsmo.transportation.org/Pages/connected_vehicles_new.aspx
[52] https://www.fhwa.dot.gov/research/tfhrc/projects/projectsdb/projectdetails.cfm?projectid=FHWA-PROJ-09-0015
[53] http://www.cts.virginia.edu/cvpfs/
[54] https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/13069a-ads2.0_090617_v9a_tag.pdf: p.19
[55] Ibid.: p.20
[56] Ibid.: p.21

- Providing reporting and communications methods for Public Safety Officials; and
- Reviewing traffic laws and regulations that may serve as barriers to the operation of ADSs.

The NHTSA ADS policy is not binding on states wishing to take action regarding use of HAVs in their state.[57] It does not affect states' decisions with regard to permission to test ADSs on public roads. Nor does it require the submission of safety assessments by manufacturers.

State legislation affecting AV testing and use is a large topic. According to the National Conference of State Legislators (NCSL), at least 34 states and the District of Columbia have considered legislation related to AVs since 2012, and eleven states – Alabama, Arkansas, California, Florida, Louisiana, Michigan, Nevada, North Dakota, Pennsylvania, Tennessee, Utah and Virginia – and Washington D.C. have passed legislation.[58] These legislative actions differ in language and scope, but altogether seek in various ways to facilitate and/or regulate the deployment and use of AVs.

The NCSL constructed a table that summarizes enacted AV legislation. An abbreviated version, current as of 4/17/17, is reproduced Table 1.[59]

[57] http://www.ncsl.org/research/transportation/autonomous-vehicles-self-driving-vehicles-enacted-legislation.aspx
[58] http://www.ncsl.org/research/transportation/autonomous-vehicles-self-driving-vehicles-enacted-legislation.aspx
[59] Ibid.

Table 1. Enacted Autonomous Vehicle Legislation

State	Bill Number	Relevant Provisions	Effective Date
Alabama	SJR 81(2016)	Established the Joint Legislative Committee to study self-driving vehicles.	May 10, 2016.
Arkansas	HB 1754(2017)	Regulates the testing of vehicles with autonomous technology, relates to truck platooning.	April 1, 2017.
California	SB 1298(2012)	Permits autonomous vehicles to be operated or tested on public roads pending the Department of the California Highway Patrol's adoption of safety standards and performance requirements.	Sept. 25, 2012.
California	AB 1592 (2016)	Authorizes the CCTA to conduct a pilot project for the testing of autonomous vehicles that are not equipped with a steering wheel, a brake pedal, an accelerator, or an operator.	Sept. 29, 2016.
Florida	HB 1207(2012)	Defines and authorizes the testing and operation of autonomous vehicles under certain conditions. and "autonomous technology. Directs the Department of Highway Safety and Motor Vehicles to prepare a report recommending additional legislative or regulatory action to be submitted no later than Feb. 12, 2014.	April 16, 2012.
Florida	HB 599(2012)	The relevant portions of this bill are identical to the substitute version of HB 1207.	April 29, 2012.
Florida	HB 7027(2016)	Eliminates the requirement that the vehicle operation is being done for testing purposes, that a driver be present, and addresses other provisions.	April 4, 2016.
Florida	HB 7061(2016)	Provides definitions, requires a study on truck platooning, and allows for a pilot project.	Apr. 14, 2016.
Louisiana	HB 1143(2016)	Defines "autonomous technology" for purposes of the Highway Regulatory Act.	June 2, 2016.
Michigan	SB 995 (2016)	Allows for autonomous vehicles, platooning, and operation without a person.	Dec. 9, 2016.

Michigan	SB 996 (2016)	Allows for autonomous vehicles under certain conditions. Allows operation without a person.	Dec. 9, 2016.
Michigan	SB 997 (2016)	Addresses automated driving systems, mobility research centers, and manufacturer liability for unauthorized modifications.	Dec. 9, 2016.
Michigan	SB 998 (2016)	Exempts mechanics and repair shops from liability in the maintenance of automated vehicles.	Dec. 9, 2016.
Michigan	SB 169(2013)	Provides definitions, permits testing, addresses manufacturer liability for unauthorized modifications, directs submission of report by state DOT and Secretary of State.	Dec. 20, 2013.
Michigan	SB 663(2013)	Addresses manufacturer liability for unauthorized modifications.	Dec. 26, 2013.
Nevada	AB 511(2011)	Authorizes operation AVs, defines “autonomous vehicle” and directs DMV to adopt rules for licensing and operation.	June 17, 2011.
Nevada	SB 140(2011)	Addresses cell phone use while driving.	June 17, 2011.
Nevada	SB 313(2013)	Relates to autonomous vehicles human operation, operation conditions, and liability.	June 2, 2013.
North Dakota	HB 1065(2015)	Provides for a study of autonomous vehicles.	March 20, 2015.
North Dakota	HB 1202(2017)	Requires the DOT to study AVs.	Aug. 1, 2017.
Pennsylvania	2016 Act 101	Allows the use of allocated funds for ITS and AV.	Sept. 19, 2016.
Tennessee	SB 598(2015)	Prohibits banning the use of AV technology.	April 24, 2015.
Tennessee	SB 2333(2016)	Addresses AV’s integrated electronic display.	March 22, 2016.
Tennessee	SB 1561(2016)	Provides AV related definitions.	April 27, 2016.
Utah	HB 373(2015)	Authorizes the DOT to test CVs.	April 22, 2015.

Utah	HB 280(2016)	Requires a study related to autonomous vehicles.	March 23, 2016.
Virginia	HB 454(2016)	Allows the viewing of a visual display while a vehicle is being operated autonomously.	April 6, 2016.
Washington, D.C.	2012 DC B 19-0931	Provides definitions, requires a human driver to take control at any moment, restricts conversion, and addresses liability.	April 23, 2013.

Often times, legislation refers to or involves state DOTs by articulating directives or allocating responsibilities. DOTs have planning, construction, maintenance and operational responsibilities for AVs. Additionally, DMVs, which may or may not be under the jurisdiction of the DOTs, are active in considering the rules of the road for AVs.

Differing philosophies are evident in the legislative actions of influential states. In 2016, Michigan enacted Senate Bills 995, 996, 997, and 998, paving the way for pilotless AV operation, truck platooning, broad liability protections for both automated technology manufacturers and repair shops against AV modifications and repairs, and mobility research centers where automated technology can be tested. This package builds off of earlier senate bills (169 and 663, enacted in 2013) that first addressed these and other issues. California conducted public workshops related to developing regulations for testing of AVs, and subsequently adopted testing regulations dubbed the "Autonomous Vehicle Tester Program" (*13*). Among other things, this program requires those who wish to test AVs to obtain "Autonomous Vehicle Testing Permits" and to regularly submit "Autonomous Vehicle Disengagement Reports". As of April 14, 2017, testing permits had been issued to 30 different entities in the state.[60]

Pennsylvania's 2016 Act 101 (formerly SB 1267) allows for the use of up to $40 million for intelligent transportation system applications, such as CAV-related technologies, in addition to other specified uses. It helps local municipalities with these technologies, given that it only requires them to provide a 20 percent match.[61]

Local agencies are also significant players for CAVs. Evidence of local government interest in preparing for AVs includes the National League of Cities, who in April 2017 published its "**Autonomous Vehicles: A Policy Preparation Guide**" (*14*) to help cities prepare for the rollout of AVs in their communities. The guide provides an overview of AV technology and answers frequently asked questions around AV manufacturers, public policy considerations, municipal coordination, and infrastructure investment. The report recommends that:[62]

1. Cities should start planning now;
2. Policy development must have the right people at the table, including city staff in charge of planning and transportation, procurement, IT, and law enforcement;
3. Cities should track and monitor federal and state developments and make sure their interests are voiced; and
4. Cities should begin planning infrastructure needs and building data and computing capacity to take advantage of an automated mobility future.

In March 2017, a group of transportation, economics and urban planning professionals released "**Driverless Future: A Policy Roadmap for City Leaders**" (*15*), which seeks

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[60] https://www.dmv.ca.gov/portal/dmv/detail/vr/autonomous/testing
[61] http://www.legis.state.pa.us/cfdocs/legis/li/uconsCheck.cfm?yr=2016&sessInd=0&act=101
[62] http://www.nlc.org/article/new-autonomous-vehicle-guide-helps-cities-prepare-for-a-driverless-future

to help cities prepare for the changes in daily life brought about by rideshared and ridesourced AVs. The road map offers guidance on complex issues related to AVs and their potential impact on equity, public transit, parking, land use, and real estate development. It identifies **six priorities for city leaders**:[63]

1. Leverage technology to enhance mobility: Cities and private partners should embrace smartcards, open data, and universal apps. This would allow riders to compare, book, and pay for trips that combine buses, trains, bikes and ridesharing.
2. Prioritize and modernize public transit: Cities and transit agencies should focus on high-ridership, high-frequency light rail and bus rapid transit systems while driverless shuttles provide first- and last-mile connections for riders.
3. Implement dynamic pricing: To reduce congestion and create a level playing field between public and private transportation, cities should consider dynamic road pricing plans that vary by origin and destination, number of passengers, congestion, and/or household income.
4. Plan for mixed-use, car-light neighborhoods: AVs can unlock demand for living and working in mixed-use neighborhoods – whether they are urban or suburban. To shape this demand, cities should plan for and incentivize mixed-use development, overhaul parking requirements, and reevaluate new transit projects.
5. Encourage adaptable parking: Fewer personal cars means fewer parking spaces, especially in city centers where much of the land use is taken by parking garages or lots. Parking garages should be built with housing or office conversion in mind.
6. Promote equitable access to new jobs and services: To support disadvantaged populations, cities should encourage public and private operators to provide alternative payment methods, access via dial-a-ride and equitable service coverage.

Further evidence of local government interest in preparing for AVs is demonstrated by the October 2016 launch of the **Bloomberg Aspen Initiative on Cities and Autonomous Vehicles**, a program for global mayors to work together over the course of a year to prepare their cities for the emergence of AVs led by Bloomberg Philanthropies and the Aspen Institute. Specifically, the initiative seeks to harness experts and data to accelerate cities' planning efforts, and produce a set of principles and tools. The inaugural cities in the initiative include Austin, TX; Los Angeles, CA; Nashville, TN; and Washington, D.C.[64]

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[63] http://driverlessfuture.webflow.io/

[64] https://www.bloomberg.org/program/government-innovation/bloomberg-aspen-initiative-cities-autonomous-vehicles/

3. New and Emerging Technologies Currently Influencing Mobility

Smart cities, cybersecurity and privacy, big data, and shared mobility are four core technologies closely related to CAVs, and having the potential to further reshape mobility.

3.1 Smart Cities

Around the world, cities are home to 55 percent of the world's population and account for around 85 percent of GDP.[65] The implementation of smart city designs and technologies could potentially change the way a city functions, improving energy efficiency, resource management, and overall quality of life for residents. Merrill Lynch projects that smart cities can reduce energy use by 30 percent, and traffic delays and water loss by 20 percent.[66]

3.1.1 Description, Trends and Applications

The term "smart city" was coined to encompass the dramatic increase in data streams that are becoming available to city managers, and how cities could make better decisions through smarter, more-efficient decision making. The smart city movement coalesced loosely around several key city functions that happened to become much more amenable to quantification and analysis:

- Transportation;
- Energy;
- Water; and
- Waste disposal.

Transportation is high on city leaders' lists. For example, facilitation of electrified vehicles— and attendant charging needs—has been taken up in a number of American cities. Such deployments have been created by automakers, energy companies, and newer players who specialize in customized electric vehicles combined with mobility service business models.

Transportation within a smart city is assisted by the open and transparent provision of data and other resources not just to transportation planners and other city leaders, but also to third parties who are looking to develop market-oriented solutions to mobility, as well as directly to drivers who can utilize real-time information to optimize commutes and parking decisions:[67]

When cities made certain transit and public service vehicle (taxi) data available, a host of trip planning and modal connection services and smartphone apps followed.

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[65] http://workplaceinsight.net/wp-content/uploads/2017/03/Thematic-Investing-Smart-Cities.pdf
[66] Ibid.
[67] http://onlinepubs.trb.org/onlinepubs/circulars/ec208.pdf

Another early adopter has been parking information and services. Smart parking is based on the notion that the incoming driver could be provided with useful information on parking location and pricing, and allow for more purposeful parking behavior.

3.1.2 Smart City Challenge

Beginning in December 2015, the U.S. DOT undertook a prominent effort to convene, publicize, and catalyze smart cities through the $50 million **Smart City Challenge**, supported by U.S. DOT and Vulcan Inc., focused on consolidating data-driven ideas to make transportation safer, easier, and more reliable. The Smart City Challenge attracted:

- Approximately 300 companies interested in participating in the Challenge;
- 78 applications, leading to the naming of seven finalists (Austin, TX; Columbus, OH; Denver, CO; Kansas City, MO; Pittsburgh, PA; Portland, OR; and San Francisco, CA) in March 2016 and the winner (Columbus, OH) in June of that year; all proposals had CAVs as central enabling technologies.

Major parts of Columbus' winning proposal included:[68]

- "Smart corridors," starting with a bus rapid transit route, that use CV to improve safety, efficiency and usability;
- Precincts with automated shuttles and freight truck platooning;
- Increasing community access to new transportation options by using AVs to link an area with high unemployment to a nearby jobs center;
- Serving its low-income population by creating transit cards for them to use ridehailing or car-sharing services, even if they don't have a smartphone or a bank account; and
- Committing to work with its electric utility to expand its smart grid and then incentivizing the charging of electric vehicles during optimal times of the day.

The Smart City Challenge attracted attention to extending the benefits of the challenge beyond the winner. Many of the unsuccessful applicants plan to advance parts or all of the smart city visions proposed in their applications. Broad interest has been mobilized among private companies and nonprofits that specialize in fields such as wireless transmitters for vehicles and infrastructure, urban innovation, cloud computing, telecommunications, solar-powered charging stations for electric vehicles, engineering design software, and pedestrian- and cyclist-detection for buses.[69]

[68] http://www.governing.com/topics/transportation-infrastructure/gov-columbus-ohio-smart-city-winner.html
[69] http://www.governing.com/topics/transportation-infrastructure/gov-columbus-ohio-smart-city-winner.html

3.1.3 What to Look for at ITS World Congress 2017

Smart cities will feature prominently at ITS World Congress 2017. Of particular note are the following two components of the events:

- Executive Session 7 (ES-7), titled “**Smart Connected Cities Promote Smart Mobility**”, will bring together senior government and private sector leaders to discuss how ITS will contribute to smart cities and improvements in mobility.[70]
- The track “**Smart(er) Cities**” will present a comprehensive array of factors that influence smart cities, including several discussed in this section. Discussion topics include traffic management, business models for urban mobility, and getting a mode shift and a bigger role for transit, among others.

Further demonstrating the importance and prominence of smart cities at this year’s event is the establishment of the “**Smart Cities Education Pavilion**”, an “experiential” exhibition that will afford attendees the opportunity not just to “see how cities across the globe are using technology to create their vision of next generation integrated mobility solutions in urban settings,” but also to make smart city technologies more tangible.

The following topics are expected to be addressed:

- Status **updates on the Smart City Challenge**, including Columbus; and
- The **integration of crowdsourced information on intelligent operations centers**. With the generation of very large amounts of non-standardized, multimodal data from infrastructure, transportation and mobility modes, and the Internet of Things (IoT) ecosystem, cities are absorbing this inflow of data and putting it to use.

<u>3.2 Cybersecurity and Privacy</u>

3.2.1 Description, Trends and Applications

Cybersecurity refers to the protection against the unwanted access, control, damage, or theft of private digital property (i.e. “hacking”) by unauthorized third parties. The practice of hacking and thus the need for cybersecurity isn’t new, but the sophistication of hacks has increased significantly. A primary challenge in ensuring cybersecurity and protecting privacy is that cyber-criminals and hackers are developing elaborate scenarios to develop attacks, including:

- Man-in-the-middle attacks to eavesdrop on entire data conversations;
- Spying software to track fingerprint movements on touch screens;
- Memory-scraping malware on point-of-sale systems; and
- Bespoke attacks that steal specific data (instead of compromising an entire system).

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[70] http://itsworldcongress2017.org/wp-content/uploads/2017/04/Executive-Sessions_Final_v040317.pdf

Systems can no longer be protected by firewalls, antivirus measures, and tool-based security approaches. While mobility systems do not offer significant financial opportunities to hackers, the safety consequences of a hacked driverless vehicle are of great concern. Many observers see cybersecurity as a “must solve” technology on the path to widespread vehicle automation.

In an April 2017 interview, the ridehailing security researcher Charlie Miller, summarized what will be required to fully secure CAVs: “Their internet-connected computers, for instance, will need ‘codesigning,’ a measure that ensures they only run trusted code signed with a certain cryptographic key…Cars’ internal networks will need better internal segmentation and authentication, so that critical components don’t blindly follow commands from the OBD-II port. They need intrusion detection systems that can alert the driver – or rider – when something anomalous happens on the cars’ internal networks…And to prevent hackers from getting an initial, remote foothold, cars need to limit their ‘attack surface,’ any services that might accept malicious data sent over the Internet.”[71] Industry members recognize the challenge that cybersecurity poses and are actively developing solutions that include these and other criteria, many of which extend beyond CAVs and incorporate the entire surface transportation system.

3.2.2 Core Drivers: Players, Efforts to Convene and Publicize, and Business Models

Until recently, key players in cybersecurity tended not to be directly involved in transportation. This is now changing rapidly as consumers demand the features that come with connected vehicles, and all parties become increasingly aware of the security, safety, and privacy challenges that such connectivity presents.

In October 2016, the U.S. DOT issued federal guidance to the automotive industry for improving motor vehicle cybersecurity. **NHTSA’s Cybersecurity Best Practices for Modern Vehicles** (*16*) focuses on layered solutions to ensure vehicle systems are designed to take appropriate and safe actions, even when an attack is successful.[72]

The voluntary, non-binding guidance recommends risk-based prioritized identification and protection of critical vehicle controls and consumers' personal data. Further, it recommends that companies should consider the full life cycle of their vehicles and facilitate rapid response and recovery from cybersecurity incidents.[73] In addition to product development, the guidance suggests best practices for researching, investigating, testing and validating cybersecurity measures. The guidance specifically lists the following examples as **fundamental vehicle cybersecurity protections**:[74]

[71] https://www.wired.com/2017/04/ubers-former-top-hacker-securing-autonomous-cars-really-hard-problem/
[72] https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/812333_cybersecurityformodernvehicles.pdf
[73] https://www.nhtsa.gov/press-releases/us-dot-issues-federal-guidance-automotive-industry-improving-motor-vehicle
[74] http://www.nhtsa.gov/staticfiles/nvs/pdf/812333_CybersecurityForModernVehicles.pdf

- Control Vehicle Maintenance Diagnostic Access: Diagnostic features should be limited as much as possible to a specific mode of vehicle operation which accomplishes the intended purpose of the associated feature.
- Control Access to Firmware: Extracting firmware is often the first stage of discovering a vulnerability or structuring an end-to- end cyberattack. Encryption should be considered as a useful tool in preventing the unauthorized recovery and analysis of firmware.
- Use Segmentation and Isolation Techniques in Vehicle Architecture Design: Logical and physical isolation techniques should be used to separate processors, vehicle networks, and external connections to limit and control pathways from external threat vectors to cyber-physical features of vehicles.
- Control Internal Vehicle Communications: Sending safety signals as messages on common data buses should be avoided, and should employ a message authentication scheme to limit the possibility of message spoofing.
- Control Wireless Interfaces: Industry should plan for and design-in features that could allow for changes in network routing rules to be quickly propagated and applied to one, a subset, or all vehicles.

It has been suggested that the government establish a universal rating system — a "cyber dashboard" — to inform consumers about how well a vehicle protects drivers' security and privacy beyond those minimum standards.[75] Potential solutions are being developed. The Argus Cyber Dashboard gains situational awareness to the cyber-health status of fleets, receives alerts and responds in real-time to cyberattacks.[76] Harman's ECUSHIELD is embedded software that seeks to eliminate threats in real time in-vehicle networks.[77]

In Europe, discussions include the development of an assurance methodology the industry can use to ensure all components and systems used in vehicles are tested to meet relevant cybersecurity standards. Advocates envision that such methodology would provide the foundation for a new consumer ratings system similar to the Euro NCAP car assessment program for vehicle safety.[78]

Non-governmental organizations, industry and stakeholder groups have been formed to specifically focus on automotive cybersecurity. **Auto-ISAC (Automotive Information Sharing and Analysis Center)** was formed in July 2015 as a collective effort by the auto industry to establish a secure platform for sharing, tracking and analyzing intelligence about cyberthreats and potential vulnerabilities. Auto-ISAC operates as a central hub that allows members to anonymously submit and receive information to help them more effectively counter cyberthreats in real time.

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[75] https://www.congress.gov/bill/114th-congress/senate-bill/1806/all-info
[76] https://argus-sec.com/argus-cyber-security-secures-26m-series-b-funding/
[77] https://www.harman.com/security
[78] https://www.infosecurity-magazine.com/news/uk-tech-group-connected-car/

In July 2016, Auto-ISAC released an overview of comprehensive **Automotive Cybersecurity Best Practices** ("Best Practices") (*17*). Best Practices provide guidance to assist an organization's development in key topic areas, including:[79]

- Risk assessment and management: Risk assessment and management strategies mitigate the potential impact of cybersecurity vulnerabilities. Best Practices focus on processes for identifying, categorizing, prioritizing, and treating cybersecurity risks that could lead to safety and data security issues. Risk management processes can help automakers identify and protect critical assets, assist in the development of protective measures, and support operational risk decisions. Risk Assessment Best Practices leverage NIST 800-30: Guide for Conducting Risk Assessments and other established resources.
- Security by Design: Follows secure design principles in developing a secure vehicle, as well as the integration of cybersecurity features during the product development process. Security by Design Best Practices leverage SAE J3061: Cybersecurity Guidebook for Cyber-Physical Vehicle Systems, NIST 800–64: Security Considerations in the Systems Development Lifecycle, NIST SP 800–121 Guide to Bluetooth Security, NIST SP–127: Guide to Securing WiMAX Wireless Communications, ISO 17799: Mobile Phone Security, and other established resources.
- Threat detection and protection: Proactive cybersecurity through the detection of threats, vulnerabilities, and incidents empowers automakers to mitigate associated risk and consequences. Threat detection processes raise awareness of suspicious activity, enabling proactive remediation and recovery activities. Threat Detection and Protection Best Practices leverage NIST 800–137: Information Security Continuous Monitoring for Federal Information Systems and Organizations, ISO/IEC 30111: Vulnerability Handling Procedures, and other established resources.
- Incident response: An incident response plan documents processes to inform a response to cybersecurity incidents affecting the motor vehicle ecosystem. Best Practices include protocols for recovering from cybersecurity incidents in a reliable and expeditious manner, and ways to ensure continuous process improvement. Incident Response Best Practices leverage NIST SP 800–61: Computer Security Incident Handling Guide, ISO/IEC 27035:2011 Information security incident management, and other established resources.

Longstanding and prominent **cybersecurity companies**, as well as newly formed companies, are pursuing the automotive and CAV market. Examples include:

- Argus Cyber Security provides carmakers a unique Intrusion Prevention System (IPS) that prevents a vehicle's critical components from being hacked in real-

[79] https://www.automotiveisac.com/assets/img/executive-summary.pdf

time. It also generates reports and alerts for remote monitoring of a vehicle's cyber-health.[80]

- Autoimmune is a cybersecurity company focused on securing modern automobiles, and helps design, plan, build, and validate secure products, software, and architecture.[81]
- Battelle helps industry and government analyze and develop solutions to vehicle cybersecurity threats through hardware and software vulnerability discovery, reverse engineering, cyber forensics and specialized tools and facilities.[82] The company also hosts an annual Auto Cyber Challenge in Detroit that gathers students, scientists, government personnel, and auto industry engineers to help study and stem future automotive security threats."[83]
- Cymotive was formed in 2016 by Volkswagen and three Israeli cybersecurity experts to "develop advanced cybersecurity solutions for next-generation connected cars and mobile services."[84]
- Green Hills Software offers open architecture integrated development solutions to address deeply embedded, absolute security and high-reliability applications. It also started an "Autonomous Vehicle Open Platform" to facilitate the security and management of AVs and Universal Control Segments (UCS) in the embedded and special-purpose computing market; this company has been engaged by a number of national stakeholders in CAVs.
- Karamba Security's technology attempts to head off hackers by "hardening" the controllers, or small computers, within a vehicle that are externally-connected.[85]
- Mission Secure Inc. (MSi) uses a proprietary methodology developed by the University of Virginia with the Department of Defense for protecting physical systems and AVs.[86]
- Mocana sells a core of cryptosecurity products to protect the in-vehicle infotainment system.[87]
- Perseus' Xen ARM-based virtualization security solution protects the connected car's operating system from malware and DDoS attacks by dividing its native domain and other domains.[88]
- Security Innovation was founded in 2002 and now is focused on securing V2V communication, among other things.[89]

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[80] https://argus-sec.com/solutions/
[81] http://www.autoimmune.io/business-areas
[82] https://www.battelle.org/government-offerings/national-security/cyber/mission-focused-tools/vehicle-cyber-security
[83] https://www.battelle.org/government-offerings/homeland-security-public-safety/transportation/transportation-operations/connected-vehicles
[84] https://www.volkswagen-media-services.com/en/detailpage/-/detail/Volkswagen-enters-into-cooperation-with-top-Israeli-experts-to-establish-an-automotive-cyber-security-company/view/3949027/7a5bbec13158edd433c6630f5ac445da
[85] https://techcrunch.com/2016/04/07/karamba-security-raises-2-5-million-to-keep-hackers-out-of-connected-cars/
[86] https://globenewswire.com/news-release/2015/01/13/697093/10115383/en/Mission-Secure-Inc-Perrone-Robotics-and-University-of-Virginia-Demonstrate-Cyber-Attacks-and-Protections-on-Autonomous-Ground-Vehicles.html
[87] https://pando.com/2014/05/06/mocana-thinks-the-internet-of-things-could-become-the-internet-of-headaches-if-we-dont-make-it-secure/
[88] http://www.zdnet.com/article/kakao-venture-firm-invests-in-connected-car-security-startup/

- Symantec is a cybersecurity giant who, in 2016, introduced Anomaly Detection for automotive to protect against zero-day cyberattacks in modern connected vehicles.[90]
- Thales e-Security is a global provider of data encryption and cybersecurity solutions.[91]
- Trend Micro offers a software development kit to bring vehicle cybersecurity in line with the IoT by protecting vehicles against cloud and network-related threats.[92]

Companies are also establishing **projects, internal efforts, and partnerships** to pursue the CAV market and/or protect company products. Some notable examples include:

- Toyota Infotechnology Center and Fujitsu established a relationship in April 2015 to improve the security of vehicles by, for example, encrypting information to be exchanged among the electronic control units (ECUs) of a vehicle and between an ECU and data center.[93]
- Intel launched the Automated Security Review Board (ASRB) in September 2015 to foster collaboration in the connected vehicle sector by focusing on cyber-physical systems that control everything inside the vehicle, among other things.[94]
- In September 2015, Giesecke & Devrient (G&D) and IBM teamed up to work on a new connected vehicle security solution with the intent to make car hacks much more difficult in the future.[95]
- Renesas Electronics Corporation and ESCRYPT announced in November 2016 a collaboration on an integrated hardware and software platform solution that provides protects automotive electronic control units (ECUs);[96] ESCRYPT was involved in developing the U.S. DOT's V2X security system used in pilot deployments such as Ann Arbor.
- Future of Automotive Security Technology Research (FASTR)[97] is a nonprofit consortium founded by Aeris, Intel and Uber in 2016 that delivers precompetitive technological building blocks such as whitepapers, reference architectures, code samples, workshops best known methods, and other resources that automotive manufactures can use across their supply chains[98] to enable innovation in automotive security.

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89 https://www.securityinnovation.com/company/news-and-events/press-releases/security-innovation-teams-with-autotalks-to-provide-exceptional-v2x-security
90 http://telematicswire.net/symantec-launches-anomaly-detection-for-automotive-cybersecurity/
91 https://www.thales-esecurity.com/company
92 http://www.itpro.co.uk/security/security/27406/this-software-wants-to-protect-your-connected-car-from-iot-hacking
93 http://techon.nikkeibp.co.jp/english/NEWS_EN/20150409/413442/
94 https://newsroom.intel.com/news-releases/intel-commits-to-mitigating-automotive-cybersecurity-risks/
95 https://www.iot-now.com/2015/09/22/37125-giesecke-devrient-teams-up-with-ibm-on-new-connected-vehicle-cryptographic-security/
96 https://www.renesas.com/en-us/about/press-center/news/2016/news20161109.html
97 https://fastr.org
98 https://www.scmagazine.com/fastr-initiative-invites-industry-pros-to-help-secure-connected-cars/article/637293/

Also of interest are efforts to address the cybersecurity of transportation infrastructure. One such effort was launched by the NCHRP in early 2017. **NCHRP 03-127 – "Cybersecurity of Traffic Management Systems"** – seeks to develop transportation infrastructure cybersecurity guidance for state and local transportation agencies. It will look at ways agencies can mitigate the risks from cyber-attacks on the field side of traffic management systems and, secondarily, on informing the agency's response to an attack. The guidance will address the vulnerability of field devices, field communications networks, and field-to-center communications, and will recommend actions that agencies should follow to protect those systems and properly react in the cases of emergency.[99]

3.2.3 What to Look for at ITS World Congress 2017

Cybersecurity and privacy will be covered in both the Executive Sessions and in a dedicated track at ITS World Congress 2017:

- Executive Session 7 (ES-5), titled "**Securing Critical ITS Infrastructure in a Connected World**" will "address the policies needed and best practices that can be used to secure our ITS systems, assuring the public they are safe when using connected transportation systems."[100]
- The track "**Data, Security and Privacy**" will include pertinent topics including business intelligence and data analytics, data mining for traffic monitoring, and the balance between driver's security and privacy data.[101]

The following topics may be addressed:

- The **status of CAV standards and regulations**.
- **Data collection, sharing, and ownership**. Areas to consider are vehicular infotainment systems, vehicular "black boxes" and diagnostic systems, and sensor data.
- **Advancement and adoption of over-the-air (OTA) update technologies**. Given that many of the most notorious hacks have been "zero-day exploits" that rely on out-of-date computer operating systems, look for discussion on how to best keep vehicular operating systems updated. Dissemination and use of OTA updates will receive consideration.
- **Discussion on and OEM's and others' adoption of the tools required to fully secure CAVs**, including codesigning, internal segmentation and authentication, intrusion detection systems, and limiting a vehicle's "attack surface".

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[99] http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4179
[100] http://itsworldcongress2017.org/wp-content/uploads/2017/04/Executive-Sessions_Final_v040317.pdf
[101] http://itsworldcongress2017.org/program/

3.3 Big Data

Some observers believe that data collection and analytics in the era of CV and AV is one of the major challenges facing state and local agencies. To quote the U.S. DOT's Beyond Traffic (*18*)[102]: "In a big data world, public agencies will need to develop their capacity to collect, store, analyze and report data." Not only do CV and AV offer new data streams for new purposes, but many existing network monitoring functions could be replaced by the use of "probe" data from vehicles. State and local agencies will need to integrate new data streams with more conventional databases. Consideration will also be given to the provision of open data, as well as commercial arrangements for providing certain data and information.

The ownership of CV and AV data is a key issue for discussion. Access to data generated and collected in vehicles needs wide consideration involving a full range of stakeholders.

3.3.1 Description, Trends and Applications

The premise of big data refers to the use of predictive analytics or other certain advanced methods to extract value, including unanticipated value, from data, and seldom to a particular size of data set. Accuracy in big data may lead to more confident decision making, which can mean greater operational efficiency, cost reduction, and reduced risk.

In addition to the number of connected devices increasing dramatically, the trendline also indicates that the amount of data produced will as well. IBM states that "Every day, we create 2.5 quintillion bytes of data — so much that 90 percent of the data in the world today has been created in the last two years alone."[103] The challenges of big data include analysis, capture, data curation, search, sharing, storage, transfer, visualization, and the security and privacy of information.

The **essential characteristics of big data** are the following "four Vs", and it is apparent that CV and AV data meet all four descriptors:

- Volume refers to the difficulties experienced by traditional infrastructure to handle enterprises that are awash with ever-growing data of all types, easily amassing terabytes (even petabytes) of information.[104]
- Velocity refers to the increasing speed at which data is created and the speed at which it can be processed, stored, and analyzed. The question is: what can we do to improve the response time to highly perishable, time sensitive data whose usefulness diminishes over a short period of time?[105]

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[102] https://www.transportation.gov/sites/dot.gov/files/docs/BeyondTraffic_tagged_508_final.pdf
[103] https://www-01.ibm.com/software/data/bigdata/what-is-big-data.html
[104] Addressing Data Volume, Velocity, and Variety with IBM InfoSphere Streams V3.0. Page 4 http://www.redbooks.ibm.com/redbooks/pdfs/sg248108.pdf
[105] Ibid.

- Variety refers to the different types of collected data – including both structured and unstructured data, such as text, sensor data, and audio – as well as the technological ability to analyze these different data types together, leading to new insights.[106]
- Veracity refers to the quality of the data.

Applying "the four V's" to CAVs shows clearly how well they fit the definition of big data:

- CAV Volume: In November 2016, Intel's CEO Brian Krzanich stated that "In an autonomous car, we have to factor in cameras, radar, sonar, GPS and LIDAR – components as essential to this new way of driving as pistons, rings and engine blocks…Each autonomous vehicle will be generating approximately 4,000 GB – or 4 terabytes – of data a day."[107] 4 terabytes is almost the equivalent to what 3,000 people currently produce per day by using PCs, mobile phones and wearables.
- CAV Velocity: This factor is dependent on a number of "gating" items within a CAV. First are the sensors. Intel's Krzanich stated that Cameras will generate 20-60 MB/s, radar upwards of 10 kB/s, sonar 10-100 kB/s, GPS will run at 50 kB/s, and LIDAR will range between 10-70 MB/s.[108] Next are two simultaneous gating items: the speed of onboard processors to make sense of and create executable parameters based on the data, as well as the speed at which the data can be transmitted from the vehicle to infrastructure or the cloud, and subsequently executable parameters based on the data back from those two sources. For reference, Nvidia's state of the art Drive PX 2 can deliver 24 trillion deep learning operations per second[109], 5G networks can transmit and receive data as fast as 10 gigabits a second[110], and cloud computers can have eight (or more) cores and 30 GB of RAM[111] to facilitate rapid processing of complex scenarios.
- CAV Variety: Intel asserts that autonomous (and, by implication, CAV) driving data comes in three basic types – technical data, which comes from a suite of sensors and is the car's "view" of the world immediately around it; crowdsourced data, which a community of local cars takes in from their surroundings, such as traffic or changes to the road conditions; and personal data. Analyzing different types of data collected from numerous CAVs is done by technologies such as

[106] Ibid.
[107] https://newsroom.intel.com/editorials/krzanich-the-future-of-automated-driving/
[108] Ibid.
[109] https://www.forbes.com/sites/aarontilley/2016/08/22/nvidia-unveils-new-processor-for-its-self-driving-car-supercomputer/#4dff42b340f8
[110] http://gizmodo.com/what-is-5g-and-how-will-it-make-my-life-better-1760847799
[111] http://www.computerworld.com.au/article/539633/amazon_vs_google_vs_windows_azure_cloud_computing_speed_showdown/

Otonomo, a company that offers an agnostic data collection platform that serves as a broker between automakers and third parties.[112]

- CAV Veracity: CAV veracity can be affected by hardware and software. Defective or otherwise compromised hardware may include sensors damaged from on-road incidents, or connectivity infrastructure damaged from weather. Software can decrease veracity if it does not accurately process incoming sensor data, drawing inaccurate conclusions about the vehicle's surroundings, performance, or passengers.

Big data can assist with many elements of mobility. New models of data collection and usage can enable governments to make predictions about traffic and travel conditions, and help control travel patterns in their respective municipalities. This can aid cities in redesigning their infrastructure and making travel more efficient.[113]

Interestingly, a recent study used big data, including vehicle trips, household income, the percentage of residents who are below 17 or above 65 years of age, and commute mode share to form predictions as to which cities in the U.S. would be the best targets for deploying AVs.[114]

3.3.2 Core Drivers: Players, Efforts to Convene and Publicize, and Business Models

Companies undertaking CAV big data processing operations need to comply with existing privacy and data laws as well as contractual commitments and policy obligations,[115] including state level laws such as the California Online Privacy Protection Act, which was the first state law in the nation to require commercial websites and online services to post a privacy policy.[116]

In May 2016, the **Federal Big Data Research and Development Strategic Plan**[117] (*19*) was released. The Plan was built around seven focus areas:[118]

- Create next-generation capabilities by developing big data foundations, techniques, and technologies;
- Support R&D to explore the trustworthiness of data, to make better decisions and enable breakthrough discoveries;
- Build and enhance research cyberinfrastructure that enables big data innovation;
- Increase the value of data through policies that promote sharing and management of data;

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[112] http://www.pcmag.com/news/353085/connected-car-data-is-the-new-oil
[113] http://dailyfreepress.com/2017/02/05/mit-professor-presents-on-urban-mobility-big-data/
[114] http://inrix.com/resources/autonomous-vehicles-study-2017/
[115] https://www.taylorwessing.com/globaldatahub/article_big_data_us_regs.html
[116] https://consumercal.org/about-cfc/cfc-education-foundation/california-online-privacy-protection-act-caloppa-3/
[117] https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/NSTC/bigdatardstrategicplan-nitrd_final-051916.pdf
[118] https://obamawhitehouse.archives.gov/blog/2016/05/23/administration-issues-strategic-plan-big-data-research-and-development

- Understand the privacy, security, and ethical dimensions of big data collection, sharing, and use;
- Improve the national landscape for big data education and training to fulfill increasing demand for analytical talent and capacity for the broader workforce; and
- Support a vibrant big data innovation ecosystem with collaboration between government agencies, universities, companies, and non-profit organizations.

While the federal government has played a role in advancing big data issues, leading the overall charge in CAV big data are companies whose technologies or overall business models depend on the production and/or analysis of data. As illustrated in Fig 3, the three **categories of big data business models** are:

- Data as a Service (DaaS) refers to the provision of very large amounts of data to users.
- Information as a Service (IaaS) refers to the provision of insights and conclusions based on big data analyses.
- Answers as a Service (AaaS) refers to the generation of answers to specific questions that aren't necessarily dictated or limited by IaaS outcomes.

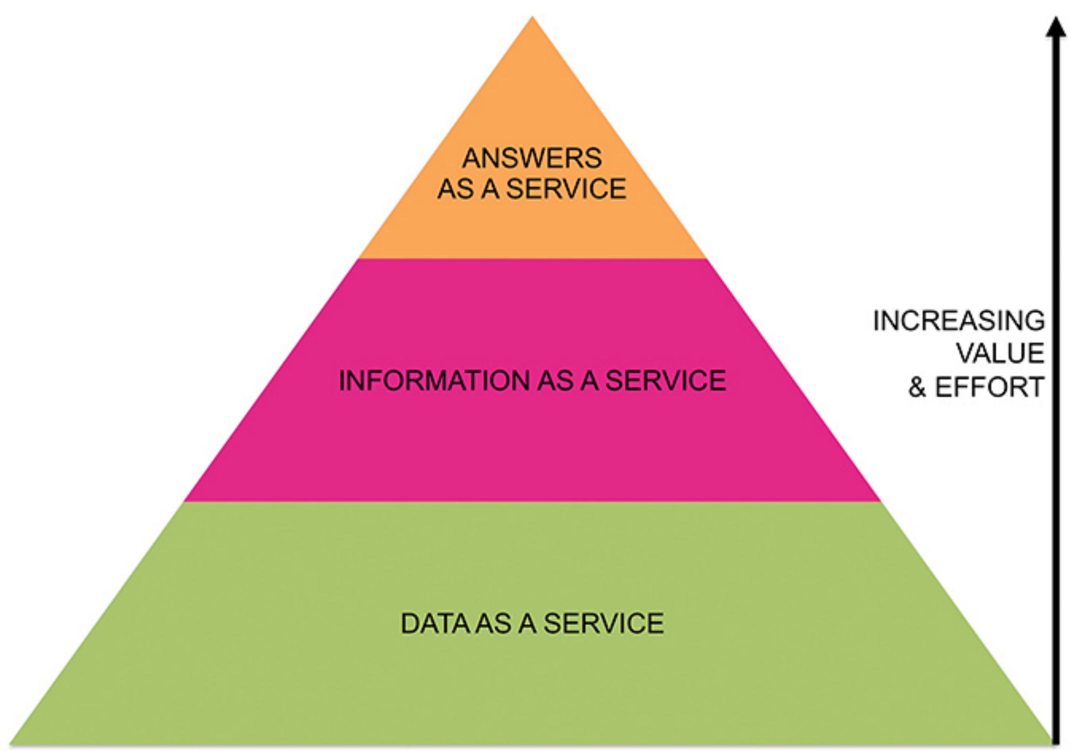

Figure 3. Three Categories Of Big Data Business Models

All of these levels of big data service should be considered by state and local agencies, and this could be an important component of the rollout of CV and AV from the agency perspective. What are the data opportunities, and in what sequence? What relationships may be needed in order to accelerate new big data activities within public agencies? And how do we ensure that state and local agencies receive useful information, rather than simply raw data, so as not to overwhelm agency time, capabilities, or resources?

Certain companies are taking actions to position themselves for big data automotive and CAV activities. IBM, Microsoft, and Amazon are each positioning their AI and cloud platforms, whose computations and insights are predicated upon big data, as solutions for navigation, in-vehicle infotainment and services, and other applications. Delphi is planting seeds throughout the big data value stream through strategic investments in companies that are developing better and faster ways to move and process data.[119] The company acquired a minority stake in the aforementioned Otonomo as well as Valens, a company that develops chips to move data several times faster than current industry standards. Delphi also purchased Movimento, which provides over-the-air software update capabilities for automotive applications.

3.3.3 What to Look for at ITS World Congress 2017

It is likely that big data will be discussed in the following sessions:

- The track "**Data, Security and Privacy**" will implicitly and explicitly address big data topics during its discussions on business intelligence and data analytics, data sharing/fusion/quality, and data mining for traffic monitoring, among others.[120]
- The track "**Smart(er) Cities**", will address traffic management, integrating transport, energy, telecoms, waste and water systems, and business models for urban mobility.

3.4 Shared Mobility (SM)

Shared mobility (SM) represents the changing nature of how people travel. Especially in highly-populated areas, the privately-owned vehicle model is evolving to one in which travelers don't necessarily own their own vehicles, drive any vehicle, or travel by car or any other singular mode of transportation. This evolution has strong components of shared vehicles, as well as Mobility on Demand.

The disruptive effects of SM are likely to be felt at the local level, but are also significant for regional and state jurisdictions. The impact of SM in cities is additional to other city and local initiatives to make personal mobility safer and more sustainable. For example, Complete Streets solutions offer support for modes other than personal vehicles, including biking, walking and transit.

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[119] http://www.pcmag.com/news/353085/connected-car-data-is-the-new-oil
[120] http://itsworldcongress2017.org/program/

3.4.1 Description, Trends and Applications

SM, often synonymous with the term "Mobility-as-a-Service" (MaaS), creates transportation services that are shared among users, including traditional public transit; taxis and limos; bike sharing; car sharing (roundtrip, one-way, and personal vehicle sharing); ridesharing (carpooling and vanpooling); ridesourcing; shuttle services; and commercial delivery vehicles providing flexible goods movement.

The trend in recent years is the broad linking and integration of these various SM modes to enable seamless point-to-point travel. While such integrated SM solutions will undoubtedly vary from one location to another, some **critical components are common** to most SM efforts:[121]

- Communication infrastructure, including widespread penetration of smartphones on fast networks; high levels of connectivity; secure, dynamic, up-to-date information on travel options, schedules, and updates; and single, cashless payment systems; and integration of physical infrastructure that enables transfer between transportation services.
- Data providers comprise one of the intermediary layers between the transportation operator and the end user. They manage the data exchange between the multiple service providers, provide the application programming interface (API) gateways, and provide analytics on usage, demand, planning, and reporting.
- Transportation operators comprise the largest group within any SM system. SM is characterized by a growing army of small-scale private providers, each offering a specific service and requiring a separate interface and payment mechanism.
- Trusted mobility advisors comprise the newest and least-known component of SM by linking the services of the various private and public operators, arranging bookings and facilitating payments through a single gateway.

Today, some 40 million people use app-enabled carpooling services, and the usage of ridehailing apps has grown rapidly to over 70 million users.[122] As this number continues to increase, attention will be drawn to assessment of the impacts of SM on traffic congestion and personal mobility. Some initial studies are available, but are too few to draw general conclusions.

A September 2016 study by Arizona State University leveraged a unique data set combining data from Uber and Texas A&M Transportation Institute's Urban Mobility Report to examine whether the entry of Uber car services affects traffic congestion. The study found empirical evidence that ridesharing services such as Uber significantly

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[121] https://dupress.deloitte.com/dup-us-en/deloitte-review/issue-20/smart-transportation-technology-mobility-as-a-service.html
[122] http://www.prnewswire.com/news-releases/digital-transformation-of-the-automotive-industry-set-to-pave-way-for-new-revenue-streams-300434985.html

decrease traffic congestion in an urban area. The study proposes **plausible underlying mechanisms** to help explain these findings, including:[123]

- Uber increases vehicle occupancy, thereby decreasing traffic congestion. A recent survey found that occupancy levels for ridesharing vehicles averaged 1.8 passengers in contrast to 1.1 passengers for taxis in a matched pair analysis.[124]
- The low-cost travel mode of ridesharing reduces car ownership. In one case, each ridesharing vehicle replaced 9 to 13 vehicles (postponed and sold) from the road. Another study showed that 15 to 32 percent of ridesharing members sold their personal vehicles, and between 25 and 71 percent of members avoided an auto purchase because of ridesharing.[125]
- Ridesharing services can shift demand among different traffic modes. Those who use carsharing services have been shown to drive significantly less than they did before using the service, bundled their trips and increased their use of public and other non-motorized transportation.
- Uber's surge pricing can delay or divert peak hour demands. Since the price of ridesharing in peak hours can surge quite high, riders who are price sensitive and flexible in their schedule may delay the travel time or choose to use public transit instead.
- Uber increases vehicle capacity utilization. Higher capacity utilization means that drivers spend less time wandering streets searching passengers, which reduces excess fuel usage and traffic congestion.

However, SM research is generally hindered by the fact that ridesharing services are private and, thus, some if not most of their trip data is inaccessible. Alternative means to derive modal travel patterns have yielded results different from the Arizona State University study.

For instance, a January 2017 study by the University of Colorado surveyed 311 passengers over about four months in Denver, Boulder, and various suburbs on topics such as where they were going, how they would otherwise have traveled, and demographic information. It concluded that ridesharing companies increase traffic and make the transportation system less efficient in these areas by mode-shifting passengers away from transit, biking, and walking trips. Specifically, about 34 percent of people surveyed said they would have either taken transit, biked, or walked instead of using the car service. An inherent inefficiency of ridesharing – namely that a vehicle has to travel from where it is called to where the passenger is to be collected (aka "deadheading") – means that it takes 1.6 vehicle miles traveled (VMT) to move a passenger one person mile (PMT).

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[123] https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2838043
[124] http://www.worldtransitresearch.info/research/5793/
[125] http://www.rmi.org/Content/Files/North\%20American\%20Carsharing\%20-\%2010\%20Year\%20Retrospective.pdf

A February 2017 study made a similar conclusion with respect to Uber's operations in New York City. In 2013, the last year before Uber's presence was felt in the city, use of subways, buses, and bicycles grew substantially. But by 2016, net growth in travel by Uber and other TNC's far outstripped growth in those modes. Ridesharing ridership tripled between June 2015 and the fall of 2016 alone. Additionally, it took 1.2-1.3 vehicle miles of travel (VMT) to move a passenger mile of travel (PMT). As a result, ridesharing operations were found to be responsible for a 3 to 4 percent jump in citywide traffic and estimated 7 percent net addition to vehicle mileage, and were a primary cause of the 11 percent slowing of traffic in the Manhattan central business district from 2013 to 2016.[126]

The current state of ridesharing and the results of limited and sometimes conflicting studies on ridesharing led a 2016 U.S. DOT and FHWA sponsored report on "**Shared Mobility – Current Practices and Guiding Principles**" (*20*) to state that:[127]

- Shared mobility is evolving and changing, and is therefore difficult to evaluate and confusing from a public policy perspective;
- Economic and travel impacts are not known;
- Compulsory reporting should be considered; and
- Interests in data sharing need to be balanced with consumer protection.

AVs feature prominently in the emerging SM paradigm, and the two technologies are mutually disruptive. The advent of automation provides a new set of possibilities for shared-use services and the shared-use concept potentially revolutionizes the impact of automated vehicles. While initial deployments are commonly confined within geographical areas (i.e. "geofenced") to help address early stage concerns, vehicles that are both automated and shared could completely change the impact of motor vehicles in cities and could help to alleviate traffic and environmental issues.

Accordingly, virtually every **automaker** that is developing AVs is also **pursuing new SM business models or partnerships**, and most **SM providers** are **developing AV technologies or partnerships**. Examples include:

- Daimler and Uber announced an agreement in January 2017 that will see Daimler introduce and operate its own self-driving cars on Uber's ridesharing network.
- Fiat Chrysler and Waymo announced plans to start a ridesharing service together using automated Chrysler Pacifica minivans. Carpooling trials via Waze Carpool, which is owned by Waymo's parent company Alphabet (Google), led many to speculate that the eventual automated ridesharing service will be launched in-house by leveraging existing Alphabet platforms and data.[128]

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[126] http://www.schallerconsult.com/rideservices/unsustainable.pdf
[127] https://ops.fhwa.dot.gov/publications/fhwahop16022/fhwahop16022.pdf
[128] http://www.theverge.com/2017/2/7/14538064/google-waze-carpool-bay-area-waymo-uber-lyft

- Ford announced in mid-2016 its intent to have a high-volume, SAE-level-4-capable vehicle in commercial operation in 2021 in a ridehailing or ridesharing service.[129]
- General Motors and Lyft announced in early 2016 "a long-term strategic alliance to create an integrated network of on demand HAVs in the U.S."[130] GM invested $500 million in the ridesharing company, and is now applying technologies and personnel it obtained in its later acquisition of Cruise Automation to enable and begin testing the technology and service. The companies state that they will begin testing "thousands" of automated Chevrolet Bolts together in 2018.[131]
- Tesla Motors announced the formation of the "Tesla Network" in 2016. The company envisions this will be a network of its self-driving cars that operate as a ridesharing service.
- Volkswagen established the new mobility company MOIA. It aims to develop IT-based on demand offerings such as ridehailing and pooling services. While ridehailing is a key pillar of MOIA's services portfolio, the company is laying the foundation for the development of future mobility business models such as the on-demand operation of driverless cars.[132]

3.4.2 Core Drivers: Players, Efforts to Convene and Publicize, and Business Models

Consumers have increasingly embraced new mobility options and apps over the last decade. Carsharing had nearly 5 million members worldwide in 2014, up from around 350,000 in 2006, and is projected to exceed 23 million members globally by 2024.[133] There are more than 1,000 public bikeshare schemes in more than 50 countries — in 2004, only 11 cities worldwide had such programs.[134] Ridehailing services have seen similarly rapid growth. In six years of operation, Uber's global footprint has expanded to more than 500 cities in more than 70 countries.[135]

Journey planning apps, which help users identify and compare different modal options for getting to their destinations, have become commonplace, with local and global offerings available in every city. A next step may be to bring **all of these options together on a common platform**. This would enable journey planning across a range of transportation modes, offering flexible payments and personalization based on user preferences regarding time, comfort, cost, and/or convenience.[136] Examples include:

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[129] https://media.ford.com/content/fordmedia/fna/us/en/news/2016/08/16/ford-targets-fully-autonomous-vehicle-for-ride-sharing-in-2021.html
[130] http://media.gm.com/media/us/en/gm/home.detail.html/content/Pages/news/us/en/2016/Jan/0104-lyft.html
[131] http://www.reuters.com/article/us-gm-autonomous-exclusive-idUSKBN15W283
[132] https://www.volkswagenag.com/en/brands-and-models/moia.html
[133] https://www.navigantresearch.com/newsroom/global-carsharing-services-revenue-is-expected-to-reach-6-5-billion-in-2024
[134] https://www.weforum.org/agenda/2016/08/what-bike-share-data-can-tell-us-about-our-cities/
[135] https://dupress.deloitte.com/dup-us-en/deloitte-review/issue-20/smart-transportation-technology-mobility-as-a-service.html
[136] Ibid.

- Ally, based in Berlin, has built a multimodal navigation app that brings together all modes of transportation so users can make the most informed choice, including all nearby transit options that may be overlooked, such as bikeshare and carshare.[137]
- CityMapper combines public transit with cabs to create integrated routes in New York, San Francisco, LA, London, Paris, Berlin, Rome, Madrid, Tokyo and many other global cities.[138]
- Moovel was founded by Daimler with the acquisition and merger of the ridesourcing company RideScout and the mobile-ticketing service GlobeSherpa. The company offers software called RideTap, which makes it easier to find the closest available transportation option.[139]
- Moovit, launched in 2011, combines transit data with live inputs from the crowd to provide a real-time snapshot of the fastest, most comfortable routes. It operates in 90 cities including New York, LA, London, Rome, Madrid, Sao Paulo, Mexico City, and Tel Aviv.[140]
- Swiftly is a data-driven technology platform that helps transit agencies improve their operational efficiency, make smarter infrastructure investments, and better engage their riders. Its open data platform product enables agencies to more accurately predict arrival and departure times, while suggesting multimodal solutions to riders.[141]
- Transit provides transit riders with upcoming departure times for nearby lines, while providing a comparison of modal options – including ridesharing, bikesharing, and carsharing – and travel times on a single screen.[142]

The current state of the shared mobility market is volatile. We are seeing fluctuations with companies launching in some cities and withdrawing their services from others (for example DriveNow in San Francisco and Car2Go in San Diego).

The coming trend in SM may be vertical integration. Most cities have some sort of journey planner. The next step is to include both public and private transportation options, recommendation engines, and reservations/booking and payments capabilities. At present, Deutsche Bahn's Qixxit and Daimler's Moovel come closest to providing a national integrated service. Each seeks to cover the entire country, aggregate both private and public providers across a range of travel modes, and enable payments for all modes in one app.[143]

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[137] https://www.tnooz.com/article/startup-pitch-ally-a-navigation-app-deploys-its-5-million-in-funding/
[138] https://medium.com/citymapper/combining-transit-with-cars-in-cities-5ecc2cad8fac
[139] http://www.autoblog.com/2016/04/15/moovel-debut-us-mobility-daimler/
[140] https://www.crunchbase.com/organization/moovitapp#/entity
[141] https://goswift.ly
[142] https://transitapp.com
[143] https://dupress.deloitte.com/dup-us-en/deloitte-review/issue-20/smart-transportation-technology-mobility-as-a-service.html

3.4.3 What to Look for at ITS World Congress 2017

Shared mobility will be discussed in depth at ITS World Congress 2017. In the Executive Sessions, there are two sessions that deal with the subject:

- Executive Session 7 (ES-7), titled "**New Business Models**" will discuss "strong shift to sharing transport rather than owning it" and what that means for public revenue models, traditional business models, the structure of public-private partnerships and their associated risk, among other things.
- Executive Session 8 (ES-8), titled "**Mobility as a Service**" "will explore how to change suppliers' attitudes and develop new private-private partnerships."[144]

The dedicated tracks offer more coverage of SM, to be addressed in virtually every track. Of particular note are:

- The track "**Connectivity and Autonomy**", which will discuss the topic of "Shared Automated Vehicles";
- The track "**Infrastructure Challenges and Opportunities**" will discuss the topics of "Digital Infrastructure" as well as "Incorporating Mobility Trends into Transportation Models";[145]
- The track "**Smart(er) Cities**" will discuss the topics of "Business Models for Urban Mobility", "Getting a Mode Shift and a Bigger Role for Transit", and "Transportation in a Digital City";
- The track "**Data, Security and Privacy**" will discuss "Data Sharing/Fusion/Quality";
- The track "**Integrated Approach: Planning, Operations and Safety**" will discuss "Multimodal Transportation/Land Use and Jobs" and "Integrated Transportation Operations";
- The track "**Disruption and New Business Models**", which is more or less devoted to SM and related concepts. Topics of discussion will include "Mobility as a Service (MaaS)/Mobility on Demand (MoD)", "Transport and Mobility as a Software Business", "People on the Move – Transit in the Future", and "Shared Mobility".

With significant coverage of SM, we will likely see discussion on:

- How do integrated, SM options **affect traffic levels and transportation system efficiency**? A recent study by the University of Colorado indicated that Uber and Lyft may be having a negative effect on both.[146]
- **Technological and other advancements** that will help SM **overcome current hurdles** to its effectiveness and advancement. Of particular note are technologies and strategies to enable widespread ticketless travel for all modes

[144] http://itsworldcongress2017.org/wp-content/uploads/2017/04/Executive-Sessions_Final_v040317.pdf
[145] http://itsworldcongress2017.org/program/
[146] https://media.wix.com/ugd/c7a0b1_68028ed55eff47a1bb18d41b5fba5af4.pdf

on a traveler's given journey, as well as coordinated payments among the multiple modalities in order to afford the traveler a single, easy transaction for journeys.

- Updates from **cities that have piloted local versions of SM** including partnerships between transit providers and private SM.

4. Questions for Policy Makers, Planners, and Regulators

The introduction of CAVs and the other technologies discussed above clearly raises important questions for state and local agencies. These questions apply in the immediate and short term, and also in the longer term, with anticipated transformational changes. In this section, we address such questions from the perspectives of current state DOT roles and responsibilities. In Section 5, we address the issues from the perspectives of emerging considerations for state and local agencies.

The adjacent technologies of smart cities, cybersecurity, big data and shared mobility are all on the critical path for state and local agencies. This means that they all need to be considered with a sense of urgency, and agencies need to position themselves to potentially be leaders in their deployment, in concert with CV and AV. In short, the adjacent technologies are entwined with CV and AV in the following ways:

- Smart cities are already incorporating both CV and AV in project plans and designs; we hear almost daily of another city that wants to be an early adopter for AVs.
- Cybersecurity is a major issue for motor vehicles, road infrastructure and back offices. The stakes are increased with CV, and further escalated with AV; it is essential for connected and smart infrastructure to adopt commensurate security measures.
- There is no doubt that CV and AV data qualify as “big data”; there is a massive challenge for state and local agencies to identify key roles and assert leadership. The ownership of CAV data is a key issue. So far, business models based on mobility data have proven to be elusive.
- Shared mobility, in the form of ridesharing services, is likely to revolutionize the introduction of AVs. SM has the potential to accelerate the rate of AV deployment and influence the roadway and traffic environments where large concentrations of AVs may first appear.

The work of the AASHTO CAV Executive Leadership Team (ELT) during 2016 focused on pressing policy issues arising from the imminent deployment of AV, along with CV, and identified a number of high-level issues, many of which would impact state and local agencies. These issues include:

Roles of Different Levels of Government
There is a need for leadership in the development of nationally-applicable guidelines for the introduction of AV; these guidelines should articulate the roles and responsibilities of all levels of government, including federal, state, county and local; the need for, and application of, standards for AV-friendly infrastructure should be included. *As we have noted, there has been significant AV policy activity at both the federal and state levels. There has been less policy activity at the local level, and cities will look to state agencies for guidance and assistance.*

CV Wireless Spectrum
The biggest early-stage risks to CV and AV deployment are (i) the availability of quality 5.9 GHz spectrum and (ii) the security and privacy of the networked technologies used in CAVs. *The 5.9 GHz spectrum issue has not yet been resolved. Meanwhile, the industry ecosystem has revealed differing viewpoints on the value of DSRC. Significant security concerns have also been expressed in relation to CV.*

Interoperability
The interoperability of CV and AV throughout the country, crossing state borders and in cities and regions, is a critical success factor for the deployment of CAVs; policies are needed to make clear the responsibilities of industry and government, including agencies at all levels. *National standards, the national CV development process led by U.S. DOT, nationally-significant CV deployments, and the work of national stakeholders like AASHTO, tend to ensure that interoperability is not a major challenge for CV. In the case of AV, we do not expect major technological differences across the country. Differences in AV "rules of the road" could be an issue, and perhaps interpretation of AV systems' declared operating environments.*

Access to AV Data
To bring about a state of AV readiness, meaningful exchange of information between industry and government is essential; voluntary exchange of relevant information and data pertaining to each side's experiences with AVs should be carried out in a conducive setting. Associations and independent organizations could play an important role in creating the right environment and creating a playing field for information exchange. *While analysis of CV data has been an important part of CV model deployments and regulatory decisions, AV data is closely held by all AV developers.*

Data Collection and Analytics
Data streams generated by CV and AV will have high value from the perspectives of transparency and early risk detection, management of the network and entrepreneurial purposes. At an early stage, policies are needed to set the stage for data access provisions. State and local agencies will need advanced data tools for network management with increasing influence of CV and AV. Data-related business models will also need to be developed.

Public Outreach and Education
AV is not well understood by the public, nor is it fully accepted. State and local agencies need to take a public position on AV through a comprehensive public outreach and education program. Such a program should include travelers, elected officials and public and private entities in the AV ecosystem. All constituencies need to contribute to the AV roadmap, and assist in developing clear messaging.

Planning Assumptions and Scenarios
Agencies require a common set of planning assumptions, scenarios and tools in order to include CV and AV in long-term planning and budgetary issues. The wide deployment

of AV in particular will strongly influence agency planning activities, and agencies need to be able to select from a solid set of scenarios and time frames.

In addition to these policy-level issues, CV and AV raise important questions in specific areas of state DOT responsibilities, as raised in the remainder of this section.

4.1 Infrastructure and Operations

Wide deployment of CV – beyond demonstrations and trials – will require CV to be integrated into state DOT operations. The technology is reasonably mature but the application of best practice still needs development. On the other hand, AV covers a wide field of technology that is still developing, and many questions exist regarding infrastructure preparation and maintenance.

Questions include:

- How should CV be interfaced with ITS architectures and deployments?
- What will be the next step after SPAT?
- What infrastructure preparations and provisions may be required for AV? What role will be played by specifically-designed lanes?
- Who will maintain those lanes – specifically, their lane lines – and will these lines be consistent across jurisdictions?
- What forms of support could CV provide for AV?
- What lessons are learned from trials and demonstrations? What are the next steps to full deployment?

4.2 Safety

From a safety perspective, CV and AV are at very different points along their paths to deployment. CV has been developed in the U.S. with federal government leadership to provide an unprecedented step forward in safety, with 80 percent of serious crashes addressable by V2V technology. In contrast, AV is the product of highly innovative tech and automotive sectors and has many attractions for users. The federal government wishes to advance highly-automated vehicles for their potential in avoiding crashes; nevertheless, there are concerns about unforeseen safety risks in the early stages of AV deployment.

Remaining safety questions for CV deployment include:

- What is the influence of the density of CV deployment in the traffic stream?
- How can deployment density be increased?
- How can the benefits of CV be extended to vulnerable road users, including pedestrians and cyclists?

Important issues for AV deployment include:

- Interactions between automated and conventional, human-controlled vehicles;
- The need for the human occupant to resume control from time to time;
- Ethical considerations and tradeoffs, whereby programmed AVs – rather than humans – will handle no-win, life-threatening scenarios, such as the notorious "trolley problem"[147], whereby the only possible choices are between killing the car's passenger or an innocent bystander;
- Safe stop capabilities in the event of automated system interruptions, and the provision of locations for safe stops; and
- Role and potential licensing of AV passengers, as operators.

The most immediate safety questions surround the assessment and approval of automated systems for use on public roads. As discussed in 2.3.1, NHTSA is encouraging manufacturers, and perhaps mobility service providers, to submit safety assessment documentation. This assessment would include nominating the intended operating environment, and describing applicable scenarios that have been tested. What will be the position of state and local agencies when it comes to the local operation of such systems? Does the agency have a say in intended operating environments, and where they may exist in state and local road and traffic networks? Should the agency take action to obtain and promulgate relevant roadway data to assist HAVs?

Similarly, immediate safety issues apply to the automated system as a "driver" and applicable rules of the road. What is the right balance between support for industries and innovation versus safety precautions for AV testing and operation? What AV safety and performance information should be provided by manufacturers? What information must be provided in the event of accidents and incidents? Is there a role for "naturalistic" performance data? How should AV crashes be investigated? What information should be retained by the AV and collected by the agency? What are the appropriate crash metrics and statistics for AV, and how should performance baselines be established?

Finally, there are AV safety issues that relate closely to the day-to-day business of state and local agencies. The ability of AVs to recognize roadworks sites and city construction sites will be of great consequence for roadway and city managers. The safety of automated systems used in heavy trucks is a challenging issue and requires specific consideration by state agencies, as discussed below. The ability of cities to deal with AV safety issues in dense, complex environments is in question – who will take leadership?

4.3 Freight Movement

CV and AV both have specific significance for freight vehicles, as distinct from personal vehicles. In the case of CV, model deployments have developed specific applications for large freight vehicles, and have developed specific solutions with regard to issues

[147] https://www.wired.com/2017/03/make-us-safer-robocars-will-sometimes-kill/

such as antenna placement. In the case of AV, freight vehicles are considered to be worthy early adopters. Commercial solutions have been developed in the cases of truck platooning (e.g. Peloton) and truck automation via retrofit (e.g. Otto). Truck platooning is an interesting case in that it combines AV and CV technologies. On-road testing of truck automated systems occurs in a commercial delivery environment and entails case-by-case review by agencies.

CV and AV policy for heavy trucks is generally lagging personal vehicles. In the case of automated systems for use in heavy trucks, the Federal Motor Carrier Safety Administration (FMCSA) is reviewing NHTSA's safety assessment guidance for application to heavy trucks. The latest NHTSA ADS guidelines apply to the design aspects of heavy-duty trucks and buses, but specifically exclude interstate motor carrier operations and commercial motor vehicle drivers.

State DOTs have important responsibilities in regulating highway freight vehicles, and questions raised by CV and AV include:

- Routes that are appropriate for truck platooning;
- Platoons of trucks from different manufacturers;
- Meeting state requirements for minimum headways;
- Requirements for truck automation demonstrations; and
- AV safety assessment applicable to heavy trucks in depot-to-depot testing and demonstration environments.

4.4 Policy, Standards, and Harmonization

As we have seen, CV and AV are different technologies and still largely follow different deployment paths. From a state DOT policy perspective, AV may involve the support of CV. AV strategy is also tightly attached to the additional supporting technologies of cybersecurity and big data. And the AV deployment curve will be strongly influenced by shared mobility providers, smart city programs and freight operators. In the development of state DOT policy and planning, AV needs to be brought into the mainstream, and it is essential to give full consideration to AV's supporting technologies: CV, big data and cybersecurity, as well as AVs key influencers: smart cities and shared mobility.

We have discussed CV standards and guidance, and the strong efforts of the U.S. DOT and national stakeholders to apply uniform standards across the country. A new version of CV security (Security Credential Management System (SCMS)) will soon be released. There are recent developments regarding the availability of a commercial system that uses the same root of trust as the proposed U.S. DOT SCMS.

As we have seen, automated vehicle system standards are likely to come in the form of a "quality assurance" approach. Key questions arise as to the role of state DOTs in potentially assimilating certain responsibilities for the provision and identification of AV operating environments.

These same issues will need to be addressed by local agencies, and state DOTs will be called upon to provide assistance to cities.

Issues to be considered by state and local agencies include:

- Strategies and business models for CV rollout;
- Benefits and costs of CV deployment;
- Provision of SCMS;
- Role of state DOTs in the identification of AV operating environments, and extension of those operating environments;
- Deployment of CV in support of AV, including benefits and costs;
- CV and AV information required by local agencies; and
- Partnerships in smart city programs.

4.5 Environmental Impacts

A number of CV applications are focused on reduced fuel consumption and emissions, and apply to both personal vehicles (the “green wave” approach) and heavy trucks, where wasteful stops may be reduced with signal priority enabled by V2I. CV data also provides new opportunities for environmental assessment and reporting on motor vehicle impacts.

The advent of AV raises the possibilities for more “tailored” vehicle design for specific applications. It is likely that electrification will feature heavily in AVs, along with lighter weight, evidence-based route selection and smoother driving patterns.

Transformational changes brought about by AV may upend traditional approaches to environmental impacts, with currently-unanswered big questions, including:

- Will VMT increase?
- Will transit ridership reduce?
- Will carbon footprint increase?
- How will AVs affect cities in terms of parking and street traffic? and
- What metrics should be used to evaluate the environmental impacts of AVs?

4.6 Law Enforcement and First Responders

Deployment of CV may improve compliance with certain traffic laws, for example by reducing red light running and by reducing speeding. Effects for heavy trucks, which take longer to respond and benefit from earlier, more specific signal information, could be significant.

Deployment of AV will raise some major issues for law enforcement, especially during the transition period with a mix of automated and conventional vehicles.

- How do AVs of differing manufacture deal with “discretionary” driving issues such as short-term speed limit exceedance or lane encroachment?
- Will human drivers adopt aggressive or intrusive driving strategies when interacting with AVs?
- Will conservatively-programmed AVs cause unintended consequences in traffic?
- How will enforcement officers and first responders recognize an AV?
- How will enforcement officers communicate with an AV, and “pull it over”?
- How will enforcement officers ensure that a stationary AV is in a safe mode?
- How will first responders deactivate AV systems after an accident?
- What guidelines may be needed for escorting, or “packaging”, heavy AV trials?
- How will municipal revenue models be affected as increasing numbers of AVs programmed not to park illegally or incur traffic citations reach roadways, potentially depriving agencies of revenue streams?

5. Emerging Considerations Driven by Automation

5.1 Land Use & Planning

The arrival of HAVs could have significant implications for land use and planning standards and protocols. These implications are driven by the ways in which machines driving vehicles differ from humans driving vehicles.

For instance, the total number of roadways, overall width of roadways, numbers of lanes per roadway, and the width of each lane within a roadway are currently set based on factors such as the expected quantity and size of vehicles on a given roadway, distances by which human driven vehicles follow each other, and margins of errors for all of these factors to alleviate the chance of collision.

Each of these factors could be affected as roadways are occupied with increasing numbers of HAVs. With their precision guidance, control, and coordination, these vehicles may be able to coordinate routes of travel to help alleviate congestion on a given route, and may be able to occupy less space on roadways as vehicular designs change and occupy a smaller footprint. Occupied road space is also reduced as HAVs will have the ability to safely travel closer together.

As previously established, one of the primary drivers of HAVs, and thus likely one of their first deployment scenarios, is through shared mobility. These highly-automated, ridesourced vehicles won't need to park in parking structures, prompting the need to rethink land allocated for parking.

5.2 Energy Impacts

The quantity, forms, and timeframes of energy consumed in both the production and use of vehicles with highly automated features are set to change – potentially dramatically – as these vehicles become commonplace. Many have speculated that, with vehicles' enhanced precision guidance, control, coordination and crash avoidance, needs for occupant protection will reduce and HAVs could be much lighter.

The efficiency increases that come with HAVs are further enhanced by the deployment and adoption of CV technologies. For instance, Adaptive Signal Control Technologies (ASCT) receive and process data from strategically placed sensors to determine the signal phase that's optimal to maximize traffic flow. On average ASCT improves travel time by more than 10 percent; in areas with particularly outdated signal timing, improvements can be 50 percent or more.[148] This translates into real-world efficiency gains as vehicles stop less and instead maintain a constant cruising speed.

Moreover, the use of connected HAVs is conducive to electrification, and in many cases such propulsion will prove economically advantageous. One automotive supplier

[148] https://www.fhwa.dot.gov/innovation/everydaycounts/edc-1/asct.cfm

projects AVs will require 200 to 350 W to process incoming and in-vehicle data generated from on-board sensor arrays, from other vehicles, the infrastructure and the cloud.[149] This significant amount of electrical power would actually be much greater – between 1.5 kW to 2.75 kW – if a projected 90 percent reduction in energy consumption from dedicated processors fails to materialize.

Electrical needs and efficiency considerations are driving manufacturers – including GM, Nissan, Chrysler and Google – to focus on testing and deploying CAV technologies in vehicles that are hybridized, use significantly more efficient combustion engines, or are propelled solely by electricity. Thus, the emerging vehicular paradigm may be that of highly electrified, ridesourced HAVs, creating a more efficient, smaller vehicular fleet that significantly reduces energy consumption.

As previously mentioned, heavy duty trucks are projected to become more efficient as they utilize automated technologies. Independent testing done by the National Renewable Energy Laboratory (NREL) showed that lead platooning trucks are up to 5.3 percent more fuel efficient, and trailing platooning trucks are up to 9.7 percent more fuel efficient.[150] V2I technology that reduces the need for heavy trucks to stop at signalized intersections would significantly reduce energy consumed in freight movements.

5.3 Multimodal Transport (Aviation and Maritime)

Automated technologies are not only applicable to on-road vehicles, but also to those operating in the air and on the sea.

In recent years, we've seen the dramatic growth of the unmanned aerial vehicle (UAV) – aka "drone" – industry. These remotely piloted vehicles first began use in military application, but made their way to the consumer market over the past several years. Some manufacturers and innovators have examined the concept of pairing CAVs with drones. Daimler produced a vision for a concept delivery van with roof mounted drones, Local Motors produced a concept car with a traffic-identifying drone mounted on its rear, and Cincinnati-based Workhorse Group is working with the University of Cincinnati to launch delivery drones from the roof of its trucks. In late 2016, Ford announced that it was investigating ways in which drones could help AVs solve navigation problems.[151]

Yet the potential for transportation system-wide drone usage extends far beyond the integration of current-generation drone dimensions and characteristics: Several companies and a significant level of capital are developing highly-automated passenger drones. The Israeli tech firm, Urban Aeronautics, has developed a 1.5-ton passenger carrying drone that is capable of transporting ½ ton of weight and traveling at about 115

[149] http://articles.sae.org/15344/
[150] https://www.nrel.gov/transportation/fleettest-platooning.html
[151] http://thehill.com/blogs/congress-blog/technology/311245-regional-demonstrations-can-prompt-self-driving-trucks-to-work

miles per hour.[152] Dubbed the “Cormorant”, the $14 million vehicle completed its first automated solo flight in November 2016.

Similarly, the Chinese-made “EHang 184” is an electric drone capable of carrying a single passenger who weighs less than 220 pounds over 60 miles. Travel is controlled mostly by an onboard tablet inside the pod-like cockpit where a passenger selects the flight’s destination.[153] In February 2017, Dubai’s Road and Transportation Agency announced plans to deploy the vehicles in July 2017.[154] Additional automated, pilotless passenger air travel vehicles are being developed by Airbus, who proposed pilotless vehicle named “Pop”,[155] Uber, who announced plans for an on demand network of electric aircraft that can take off and land vertically, which it aims to begin testing in Dubai and Dallas by 2020,[156] and Lilium, who is developing its Electric VTOL Taxi.[157]

Highly automated maritime vehicle development and demonstration dates back several years. MIT is collaborating with Delft University of Technology and Wageningen University on project named “Roboat” focused on creating a small fleet of self-driving boats. It will first be tested in Amsterdam in 2017 to ferry commuters and goods about the city. The researchers are also working to create other “dynamic” craft and temporary floating infrastructure such as on demand bridges and stages.[158]

Private companies have been developing self-driving boats for a variety of other purposes for some years. Sea Machines, in Boston, MA, builds automated control and navigation systems for the commercial marine industry. Saildrone, in Alameda, CA, is building miniature sailboats that traverse the bay and shores to monitor fish stocks or gather environmental data.[159] Rolls-Royce sees highly automated cargo ships as the future of the maritime industry, and claims the “smart ship” will revolutionize the landscape of ship design and operation.[160]

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[152] http://www.reuters.com/article/us-israel-flyingcar-idUSKBN14N190
[153] http://fortune.com/2016/01/07/ehang184-autonomous-human-size-drone/
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[158] http://www.computerworld.com/article/3121748/emerging-technology/autonomous-boats-yes-boats-to-hit-the-water-in-2017.html
[159] Ibid.
[160] http://www.rolls-royce.com/products-and-services/marine/ship-intelligence.aspx#section-overview/remote-and-autonomous-operations

6. Opportunities at the World Congress

6.1 Leading-Edge Themes in CAV and Related Technologies

In order to assist Leadership Forum participants' preparation for the Workshop at the ITS World Congress 2017, we suggest approaching the key issues and inter-relationships depicted in Fig 4. This shows CAVs as a central topic with closely-related technologies: big data and cybersecurity. We also show the deployment of AV as being strongly influenced by smart cities, trucking applications, and shared mobility.

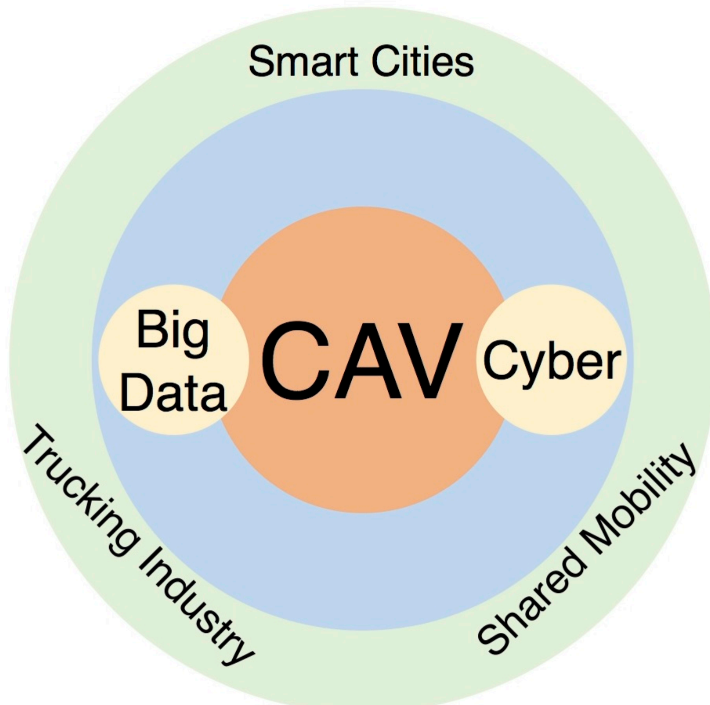

Figure 4. Key inter-dependencies for CAV deployment

Based on this model of the key issues for state and local agencies, we propose that the **major themes of the 2017 Leadership Forum Dialog** could be selected from the following.

6.1.1 Safety of AV Transition

The issue of avoiding increased safety risks during the AV transition period – when AVs mix with conventional vehicles, and AV driver/operator roles are still evolving – has emerged as a major challenge, especially given that it is a challenge likely to persist over decades, as at least some number of conventional vehicles will remain on roadways. Safety questions exist for infrastructure and traffic operation, and law enforcement.

To minimize such risks, AV early adopters may concentrate on closed communities, precincts and campuses. Important learnings are anticipated. Local agencies will need to deal with the most challenging conditions: dense, complex urban environments. Such agencies would benefit from the assistance of state DOTs.

6.1.2 Connected Infrastructure Supporting AV

National stakeholders have generated recent momentum in deploying V2I, which could play a major role in supporting and accelerating the deployment of AV. The nature and value of CV assistance to AV could be an important topic for the 2017 Leadership Forum. Further, it appears that the deployment of AV systems could follow a segmented "quality assurance" approach that would benefit from a corresponding focus on AV operating environments.

6.1.3 Emerging Business Models Based on Big Data

State and local agencies may be facing opportunities with the biggest of big data. There are significant issues with data collection, analytics and access. The aforementioned SCMS would change each vehicle's identification every five minutes, which might limit data's usefulness. And the security and ownership of – as well as rights to – CV and AV systems and data is paramount. Leadership in this field could become vital to state DOTs' long-term future.

6.1.4 Adoption of AV in the Trucking Industry

The trucking industry may represent an early adopter of AV. This industry requires specific consideration of AV deployment, not the least because truck-specific AV applications address well-defined vocational requirements. Considering state DOT responsibilities for freight corridors with increasing truck traffic, this may be a rewarding theme for the Leadership Forum.

6.1.5 State DOTs Supporting Cities

Given the importance of city CAV programs in technology deployment, the increased challenges for AVs operating in cities, and cities' relative lack of access to R&D support, state DOTs have an opportunity to provide technical and policy assistance.

6.1.6 Adoption of AV in the Shared Mobility Industry

Cities continue to play an important role in the development of the SM industry, and SM could play an important role as an early adopter of AV.

6.2 Participation in Technical Sessions, Policy Sessions, Exhibits and Demonstrations

The above six themes will be well represented at ITS World Congress 2017.

Within the Executive Session, “safely transitioning to AVs” will be addressed directly in the session titled “**Practical Aspects of Deploying Connected and Automated Vehicles**” (ES-4). Among other things, this session will discuss how automated vehicles can run alongside traditional traffic on legacy infrastructure. “Emerging business models based on big data” will also be directly addressed: The session titled “**New Business Models**” (ES-11) will discuss the large quantity of transport data and ways organizations are making money by selling it or/and using it.

“Connected infrastructure supporting AV” will be included in the sessions titled “**Resilient and Safe Infrastructure**” (ES-9) and “**ITS Deployment Policies**” (ES-3). This latter session states advocates for transportation planners’ consideration of the impacts of CAVs, and will discuss how planners and government officials are thinking about and preparing for automated vehicles. In the session titled “**Mobility as a Service**” (ES-12) AV in Shared Mobility will be a prominent topic.

The topic of “AV in the trucking industry” will be covered in “**Breaking Silos to Pave the Way to Automated Vehicles**” (ES-1) and in “**Freight Technology: How do we Ensure Public Safety**” (ES-10).

6.3 Preparation for Thursday Workshop

More information on the topics discussed in this White Paper as well as the Executive Sessions and dedicated tracks will be forthcoming as ITS World Congress 2017 approaches. The program for the Leadership Forum Workshop will be developed in consultation with Leadership Forum members, NCHRP and AASHTO. The program will include feedback on all key themes listed in Section 6.1 and will provide added focus on selected themes and issues.

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