MDOT
Michigan Department of Transportation

CAR
CENTER FOR AUTOMOTIVE RESEARCH

INTERNATIONAL SURVEY OF BEST PRACTICES IN CONNECTED AND AUTOMATED VEHICLE TECHNOLOGIES

2015 UPDATE

December 7, 2015

Sponsoring Organization:
Michigan Department of Transportation (MDOT)
425 Ottawa Street
P.O. Box 30050
Lansing, MI 48909

Performing Organization:
Center for Automotive Research (CAR)
3005 Boardwalk, Ste. 200
Ann Arbor, MI 48108

Template and Style Sheet for MDOT-CAR Research Reports
December 7, 2015

MDOT REQ. NO. 1259, Connected and Automated Industry Coordination
Task A.10. International Survey of Best Practices in ITS/CAV

Author:
Joshua Cregger, CAR

Managing Editor:
Richard Wallace, M.S., Director, Transportation Systems Analysis, CAR

Additional Contributor:
MacPherson Hughes-Cromwick, CAR

Abstract:
Connected and automated vehicle (CAV) systems can provide a variety of benefits and companies and agencies that lead research and development efforts are playing a large role in bringing these to fruition sooner. Such efforts are taking place throughout the world (especially in the United States, Europe, and Asia). This report highlights major CAV deployment efforts throughout the world and evaluates important factors for successful deployment. Using information gathered from interviews, electronic searches, and print materials, the authors determined common and contrasting themes, drivers of success, types of technology tested or deployed, and other factors to document lessons learned. By examining CAV technology development efforts globally, the authors identify best practices that will allow transportation agencies such as the Michigan Department of Transportation to strengthen their CAV programs.

ACKNOWLEDGMENTS

This document is a product of the Center for Automotive Research under a *State Planning and Research Grant* administered by the Michigan Department of Transportation.

EXECUTIVE SUMMARY

The Michigan Department of Transportation (MDOT) is both a national and international leader in connected and automated vehicle (CAV) technology and is interested in lessons learned from efforts in other states and countries related to connected vehicles, automated vehicles, and related Intelligent Transportation Systems (ITS). By learning more about how CAV technologies are deployed, managed, and operated elsewhere in the world, MDOT seeks to identify and implement best practices that will allow it to further strengthen its own CAV program. To this end, MDOT contracted with the Center for Automotive Research (CAR) to conduct an international survey of best practices and report the findings of this research to MDOT.

To accomplish this task, CAR staff conducted electronic searches for information and published material describing CAV activities throughout the world. CAR researchers then analyzed the information collected to identify common and contrasting themes, drivers of success, types of technology tested or deployed, and other factors to document lessons learned for MDOT.

To catalog the international assets in CAV technologies and achieve a better understanding of what is currently occurring with regard to testing and deployment of these systems, CAR created a database of projects and papers related to CAVs. The database was first compiled in 2010 and has been updated several time since then. It includes details on the organizations conducting research or deploying assets, the type(s) of technology used, nature of the work, applications, and descriptions of work. Over time, some projects have been completed, put on hold, or discontinued, while new ones have launched or old ones expanded. With this in mind, CAR continues to update the database. As of December 2015, the database contained 505 entries total: 101 for Asia, 189 for Europe, 201 for North America, and 20 for other regions.

This report is largely an update and expansion of previous work on domestic and international CAV programs that CAR previously conducted for MDOT. This updated report includes new information about some projects and other efforts that were already underway in earlier versions of the report, but focuses on information about additional programs not covered in previous CAR reports.

This report is intended to provide MDOT with the information needed to inform Michigan CAV decision-makers and to assist MDOT in its efforts to continue to be the national leader in CAVs.

Despite the regional differences in CAV programs observed by CAR, many overarching themes have emerged that are useful to consider with respect to technology deployment. CAR researchers have identified funding strategies that have been used to support CAV programs, factors that can affect the success of deployment, and an overall trend in convergence of connected and automated vehicle technologies. These conclusions are summarized below, and a full description of each topic is provided in the Conclusions and Recommendations section of this report.

FUNDING OPTIONS

- Requiring matching funds in budget allocations
- Pursuing funding at a national level
- Using tolls to fund programs
- Conducting private CAV research

IMPORTANT FACTORS

- Forming coalitions
- Facilitating industry competition
- Developing programmatic themes and bold goals
- Generating expertise
- Regulating technology to make a strong business case
- Creating global standards

RELEVANT ISSUES

- Increasing convergence
- Decreasing dependence on public infrastructure
- Addressing cybersecurity concerns
- Emerging regional competition

TABLE OF CONTENTS

1 INTRODUCTION

The Michigan Department of Transportation (MDOT) is a national leader among public agencies in the development and deployment of connected and automated vehicle (CAV) technology and related Intelligent Transportation Systems (ITS). MDOT understands that a national deployment of CAVs requires coordination among states. Vehicle owners in particular will expect to be able to use their CAV technology beyond their home location. As a result, MDOT requested that the Center for Automotive Research (CAR) investigate CAV-related activities underway outside Michigan, especially international examples of CAV work, for the purpose of understanding and describing overall best practices in CAVs.

1.1 CAV TECHNOLOGY

Connected vehicle technologies—sometimes referred to as Information and Communications Technology (ICT) in Europe—use part of the electromagnetic spectrum to send messages between vehicles (vehicle-to-vehicle or V2V), between vehicles and infrastructure (vehicle-to-infrastructure or V2I), or between vehicles and other devices (vehicle-to-device or V2X). Connected vehicle systems frequently use 5.9 gigahertz (GHz) frequency known as Dedicated Short Range Communications (DSRC) or cellular networks (3G/4G mobile telecommunications technology) to send messages.

Automated vehicle technologies rely on sensor technologies, such as radar, lidar (a laser-based ranging system), and cameras, to collect information about the surrounding environment. Using the collected information, an automated vehicle can partially or totally control driving functions, such as steering, acceleration, and braking.

CAV technologies include both connected vehicle technologies and automated vehicle technologies. Some systems combine vehicle connectivity and automation to produce what are referred to as converged systems.[1] For instance, various vehicle platooning projects use both communications and sensor inputs. In addition, many fully automated vehicle systems use some form of on-board connectivity to facilitate over-the-air updates.

[1] Silberg and Wallace 2012.

1.2 PREVIOUS INTERNATIONAL BEST PRACTICES WORK

In response to an earlier request to document national best practices, CAR conducted electronic searches of ongoing connected vehicle and connected vehicle-related activities outside Michigan, conducted phone interviews with connected vehicle experts outside Michigan, and met personally with knowledgeable experts. The meetings occurred mostly through attendance at a Transportation Research Board event and a brief trip to the Bay Area in California, where much of the US activity outside Michigan is concentrated. These efforts resulted in contacts with numerous organizations.[2] In 2011, 2012, 2013, and 2014 CAR conducted updates to the previous study.[3] In these updates, CAR researchers developed broader documentation of projects and best practices in Michigan, other US states, and other countries.

To investigate and analyze the extent of international CAV technology assets, deployments, and research projects, as well as to achieve a better understanding of what testing and deployment is currently occurring, CAR created a database of CAV projects and papers. This database included details on organizations conducting research, type of technology used, nature of the work, applications, and descriptions of work.

1.3 2015 INTERNATIONAL BEST PRACTICES UPDATE

This report is an update of previous CAR work on international CAV best practices done for MDOT. This report contains descriptions of numerous selected projects within the United States and across the world. These descriptions cover both completed and ongoing projects.

The major departure from previous updates is that the 2015 update includes only current and future projects. Projects covered in previous years are included in the 2015 update if new information is available. Descriptions of previously completed projects largely have been omitted from this report—details on those older projects can be found in the 2014 update.[4]

The accompanying database has been updated several times since it was originally created, both to account for its expanded scope and to ensure it remains current. In the past year, some previously covered projects have been

[2] Wallace and Sathe Brugeman 2008.
[3] Wallace et al. 2011, Wallace et al. 2012, Wallace et al. 2013, and Cregger 2014.
[4] Previous versions are available on the *Connected Vehicles* page of the MDOT website: http://www.michigan.gov/mdot/0,1607,7-151-9621_11041_38217---,00.html.

completed, put on hold, or discontinued, while new ones have launched or expanded.

As of December 2015, the database had 511 entries. Of these, 101 referred to projects and other efforts in Asia, 189 in Europe, 201 in North America, and 20 in other regions. Figure 1 displays the geographical distribution of projects throughout the world.

This report contains two appendices: Appendix A contains explanations for all abbreviations used in this report. Appendix B contains country-by-country (and state-by-state) count of connected vehicle projects in the database.

1.4 OVERVIEW OF NEW AND UPDATED PROJECTS

In North America, there are several major new developments. At the national level, the US Department of Transportation (USDOT) is expanding its *Connected Vehicle Pilot* program and has selected additional sites for its first wave of deployments. Several new automated vehicle trials are in the works on college campuses, theme parks, airports, and downtown areas. Google has expanded its trials, and other tech companies, such as Apple and Uber, may soon join in with their own. States with existing CAV testing centers, such as Michigan, Florida, and Virginia, are expanding and adding to their testing assets.

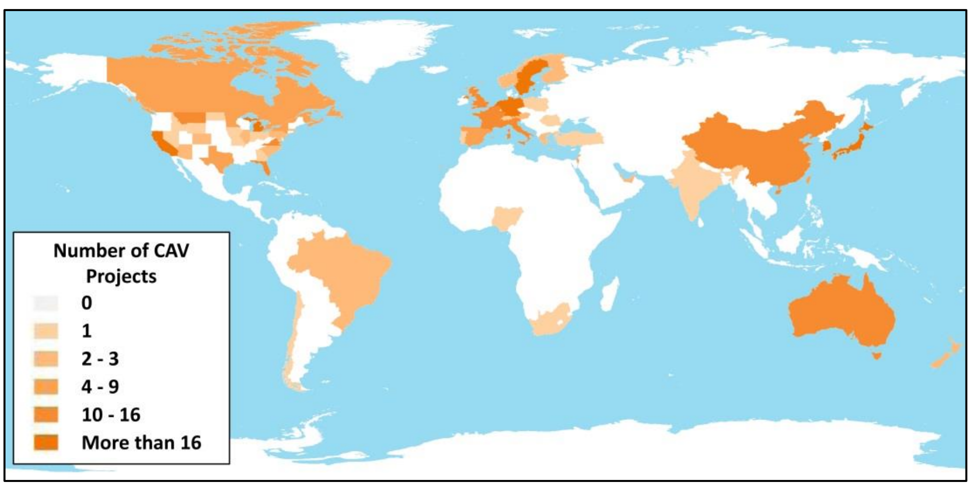

Figure 1: World Map Showing Projects by Country (State for US-based Projects)
Source: CAR 2015

In Europe, several new smaller projects have launched. The most high profile new projects are the automated vehicle pilots occurring in three cities in the United Kingdom. Similar automated vehicle pilots on public roads are slated to begin in the Netherlands. Testing continues for the Drive Me and AstaZero

Proving Ground projects in Sweden. The Netherlands, Germany, and Austria are continuing to deploy the Cooperative ITS Corridor. The FOT-Net project has entered its next phase and is now known as the FOT-Net Data project.

In Asia, many of the new CAV projects are driven by industry, with tech companies Baidu and Alibaba pursuing projects in China and automotive companies Toyota and Denso pursuing projects in Japan. The Japanese government is continuing to develop its CAV and ITS solutions with improvements to electronic tolling and other connected vehicle applications.

This update also briefly discusses the state of CAV work in other parts of the world. These areas include Oceania, the Middle East, Africa, and South America. CAV projects in these areas lag behind the efforts in North America, Europe, and Asia, and most development is focused on traditional ITS. The major exception is Australia, which has been working lay the foundation for a connected vehicle system and is preparing for initial automated vehicle testing on public roads.

1.5 ONWARDS

The remainder of this report presents CAR's findings and analysis of these findings to provide MDOT with insights into best practices. CAR's intent is to provide information needed to inform Michigan CAV decision-makers and to assist MDOT in its efforts to continue to be the national leader in connected vehicles among the states. The report is organized largely by continent and country, with cross-cutting lessons provided in the Conclusions and Recommendations section.

2 CONNECTED VEHICLE EFFORTS IN NORTH AMERICA

Within North America, the majority of connected vehicle research is conducted in the United States. A significant portion of this work has been done at the state level by state agencies and universities. The states of Michigan and California have been responsible for much of this work, but other states, such as Florida, Minnesota, Montana, New York, Texas, and Virginia, also have active research and development programs.

The approach in the United States is not totally decentralized. USDOT has taken an active role in connected vehicle research and has provided significant funding for much of the work done across the country. Much of the focus of USDOT CAV research in recent years has been related to a National Highway Traffic Safety Administration (NHTSA) regulatory decision on connected vehicle technology. Figure 2 shows the geographical distribution of projects throughout North America. Some projects are spread across several states; for mapping purposes, such projects are assigned to the state of their lead coordinator.

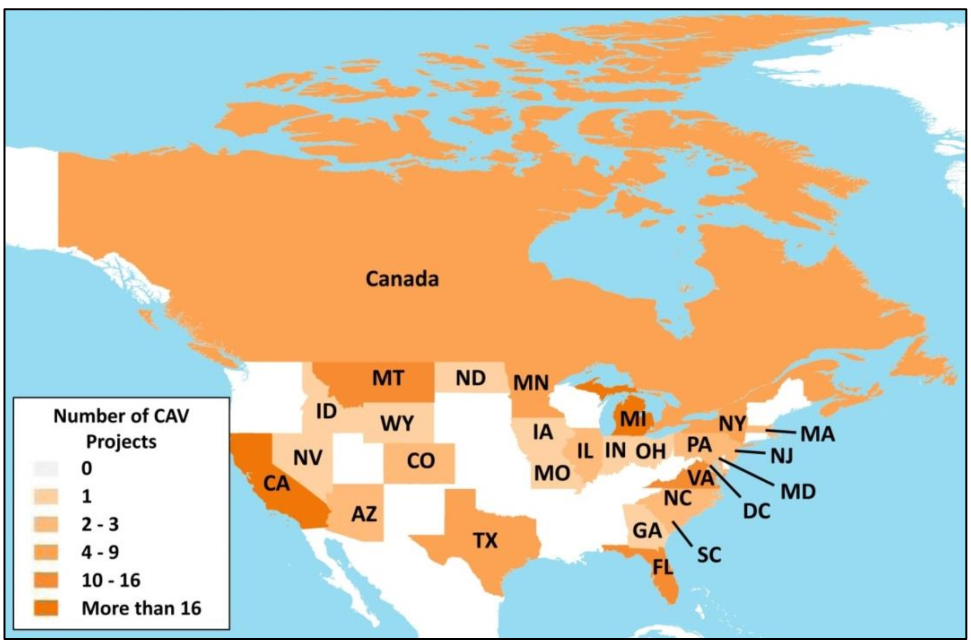

Figure 2: CAV Projects in North America
Source: CAR 2015

2.1 US NATIONAL-LEVEL PROJECTS

At the national level, the USDOT is expanding its *Connected Vehicle Pilot* program and will soon select additional sites for its first wave of deployments. In addition, several new automated vehicle trials at various stages of development. Most of these projects are limited in scope (e.g., limited to college campuses, airports, and other relatively small areas with limited trip origins and destinations). As the trials progress they may expand to coverage larger areas.

CONNECTED VEHICLE PILOT EXPANSION

In 2014, as a result of the successful results of the *Safety Pilot* activities and the NHTSA decision to pursue a connected vehicle mandate for new light-duty vehicles, USDOT announced that it would commit to additional pilot deployments to facilitate initial connected vehicle deployments in real-world settings. In 2014 and early 2015, USDOT held workshops and webinars, and in early 2015, the agency posted a solicitation for applications for the first wave of pilot deployments. In September 2015, USDOT announced successful proposals. Solicitation for a second wave of applications will occur in early 2017 with awards following later that year. All pilot deployments will be completed by September 2020.[5]

The USDOT has awarded up to $42 million for connected vehicle pilot deployments in New York, Florida, and Wyoming. In New York, on-board units will be installed in 10,000 city-owned vehicles (including cars, buses, and limousines) and roadside infrastructure will be installed throughout Midtown Manhattan and Brooklyn. The pilot in Tampa, Florida will focus on pedestrian safety using smartphones and connected vehicle technologies. The pilot in Wyoming will focus on safety and efficiency improvements in freight traffic on I-80 east-west corridor There will be another wave of pilot deployments in 2017.[6]

AUTOMATED VEHICLE TRIALS

Many automated vehicle trials are being conducted on public roads and closed testing facilities throughout the United States. The consulting firm Comet LLC, is deploying automated vehicle trials on college campuses, theme parks,

[5] USDOT 2015.
[6] ITS-JPO 2015.

airports, and downtown areas.[7] The first project has been deployed in the Tampa area around the Museum of Science and Industry. Eventually the trial will expand to include service to the University of Southern Florida and the nearby City of Temple Terrace. Another planned deployment at Fort Bragg in North Carolina, will involve automated pod-cars to transport wounded troops from their barracks to medical appointments. Additional deployments are planned for the Military Academy in West Point, New York; the SLAC National Accelerator Laboratory in Menlo Park, California; Greenville, South Carolina; Seattle, Washington; and two additional projects in Florida.[8]

Several companies are testing vehicles on public roads, at their own proving grounds, and at third-party-managed sites such as GoMentum Station in California and Mcity in Michigan. Some trials are being conducted internally as part of company research and development (R&D) efforts, some include a temporary public demonstration component, and some are intended to provide regular service to users over a longer period. While many trials have been mentioned in this section, there are undoubtedly many others at various stages of development.[9]

STATE OF DSRC FOR CONNECTED VEHICLE APPLICATIONS

In February 2014, NHTSA issued a press release announcing that it will begin taking steps that could eventually require DSRC-based V2V communication technology in all new light-duty vehicles sold in the United States.[10]

In April 2015, the Transportation Research Board (TRB) committee released a review of DSRC technology and applications to the US Congress. The TRB report noted the potential benefits of DSRC for safety applications and highlighted the potential serious risk and uncertainty related to sharing the spectrum with other, non-transportation uses.[11]

[7] Lazzaro 2015.
[8] Lazzaro 2015.
[9] Organizations such as Association for Unmanned Vehicle Systems International – AUVSI (www.auvsi.org) and Driverless Transportation (www.driverlesstransportation.com/) provide frequent coverage on these types of trials.
[10] NHTSA 2014.
[11] TRB 2015.

2.2 MICHIGAN

Michigan has a long history of CAV testing and hosts many existing CAV assets. The state is looking to leverage these assets, for example, to develop the Connected Vehicle Environment. More development is going on in Ann Arbor following the completion of the *Safety Pilot Model Deployment* as the University of Michigan Transportation Research Institute continues work on the *Ann Arbor Connected Vehicle Test Environment*, its Mcity test facility, and other CAV projects.

CONNECTED VEHICLE ENVIRONMENT

At the 2014 ITS World Congress in Detroit, General Motors (GM) CEO Mary Barra announced a plan to create a 120 mile Connected Vehicle Environment in Michigan (see Figure 3).[12] The project consortium to create the Connected Vehicle Environment includes MDOT, GM, Ford, and the University of Michigan. The project will be developed primarily along I-96/I-696 and I-94, and will also include part of US-23 and the former *Safety Pilot* site (now known as Ann Arbor Connected Vehicle Test Environment). MDOT has identified 400-470 locations where roadside units could be located. The project includes numerous applications, both V2V and V2I, such as emergency electronic brake lights, forward collision warnings, left turn assist, work zone warnings, signal phase and timing, and border wait time applications.[13] Though the $20 million pilot site application submitted to USDOT to further support the development of the project was unsuccessful, development of the Connected Vehicle Environment will continue .[14]

[12] MDOT 2014.
[13] Castle 2015.
[14] Smith 2015.

Figure 3: Michigan Connected Vehicle Environment
Source: Castle 2015

By August 2015, MDOT had installed 17 sensors and cameras on existing power poles and stoplights, 12 of which were placed along I-96 and I-696 between Milford Road and Orchard Lake Road, and five of which were placed at nearby intersections.[15]

ANN ARBOR CONNECTED VEHICLE TEST ENVIRONMENT

The *Safety Pilot Model Deployment* in Ann Arbor is being expanded from a portion of northeast Ann Arbor to cover the entire city, which is approximately 27 square miles. The number of equipped vehicles will be increased to 9,000, more than three times as many as the original *Safety Pilot*.[16] The deployment will also be renamed the *Ann Arbor Connected Vehicle Test Environment* (AACVTE).

The three-year transition began in 2014, and the University of Michigan Transportation Research Institute is now approved as the sole source to operate, maintain, and upgrade the AACVTE. During the transition, UMTRI will work to transform the deployment from the federal government-funded *Safety Pilot* effort to a self-sustaining test environment. UMTRI will also be

[15] Martinez 2015.
[16] MTC 2015.

looking for ways to create a cohesive roadmap for the AACVTE and its other research efforts, including the recently constructed Mcity test facility.[17]

UNIVERSITY OF MICHIGAN MCITY

In July 2015, the University of Michigan opened its Mcity (formerly referred to as the Mobility Transformation Facility), a 32-acre CAV technology test site operated by the Mobility Transformation Center (MTC), a public-private partnership headquartered at U-M. Mcity has five lane-miles of roads with intersections, traffic signs and signals, sidewalks, benches, simulated buildings, street lights, obstacles (e.g., construction barriers), a mechanical pedestrian, and other features (as illustrated in Figure 4 and Figure 5).[18] Work on the site began in May 2014. Several companies are already members of the MTC, including automakers Ford, GM, Honda, Nissan, and Toyota and suppliers Bosch, Delphi, DENSO, Econolite, Iteris, Navistar, Qualcomm, State Farm, Verizon, and Xerox.[19]

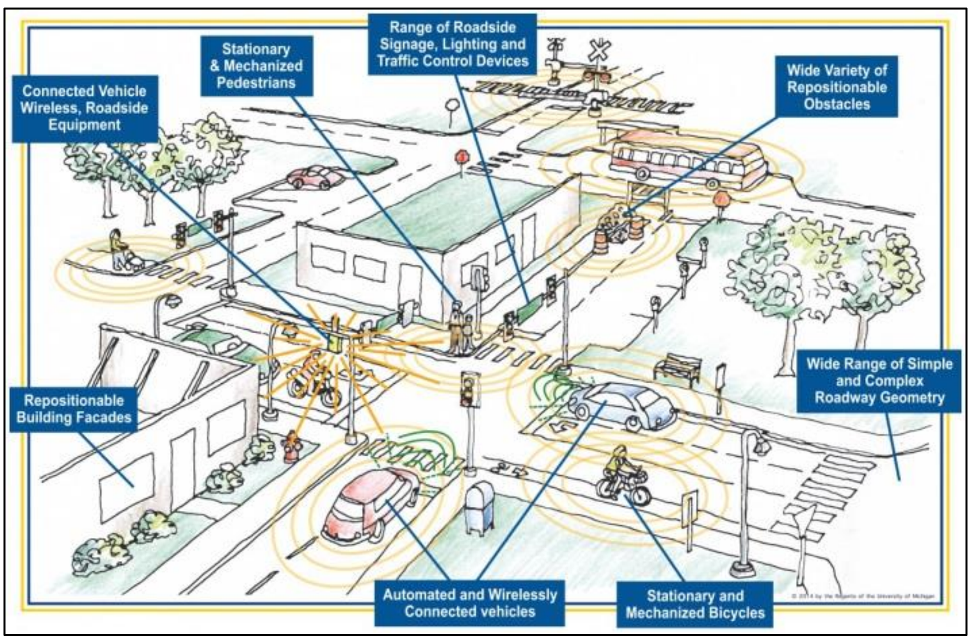

Figure 4: Mcity Concept (Artist's Rendering)
Source: MTC 2015

[17] Bezzina 2015.
[18] MTC 2015.
[19] MTC 2015.

Figure 5: Mcity Site (Aerial Photograph)

Source: MTC 2015

SMARTCARTS

In the "SmartCarts" project, the University of Michigan will test a fleet of 3D-printed, automated, low-speed electric vehicles in and around MCity and the University's North Campus. The small vehicles will integrate a traditional golf cart powertrain with a 3D-printed body from Local Motors. Students, professors, and staff will be able to use the vehicles to get to class, labs, and offices. The SmartCart project will serve as one of the first test beds for on-demand automated transit. University of Michigan's first vehicle is one of three that have been built for university research. It arrived on campus in July 2015. The university will receive a second vehicle in late 2015 or early 2016 and the two vehicles will be used to conduct a pilot at Mcity. The pilot project will last for one year and is being funded through the Mobility Transformation Center.[20]

2.3 CALIFORNIA

The state of California has long been a leader in CAV testing. Much of the previous CAV work in California centered around the state's department of transportation, Caltrans, as well as its partnerships with major universities.

[20] Cherry 2015.

California is also host to many CAV test facilities for automakers and automotive suppliers, as well as technology companies. Google has been conducting automated vehicle trials in California for several years, and rumors suggest that Apple may begin its own tests in California soon.

INTERACTIVE VOICE CONTROL TRIAL

Visa and Pizza Hut have collaborated to perform a connected vehicle trial, which would allow drivers to purchase food from Pizza Hut from their vehicles with just a few clicks on a screen that is integrated into the dash of a connected car. The system uses Bluetooth LTE communications technology. In addition to allowing customers to order from their vehicles, the system will inform Pizza Hut employees of customer arrivals. The companies are also working with Accenture, which is overseeing the system integration. A three-month test run of the program began in spring 2015 in Northern California.[21]

GOOGLE AUTOMATED VEHICLE PROGRAM

Many companies within the United States, including traditional automakers, such as GM, Toyota and Volkswagen, are developing and testing advanced automated vehicle technologies. High-tech automotive supplier firms such as Bosch, Continental, Delphi, TRW, and others are also developing advanced technologies, both in cooperation with, and independent of, the automakers. In addition, Silicon Valley firms such as Google and other tech start-ups are developing automated vehicle technology.

Google began its self-driving car project in 2009, and since then, the company has logged more than a million miles of autonomous driving experience among its test vehicles, mostly in and around Mountain View, California.[22] Until recently, all of Google's self-driving test vehicles have been commercially available vehicles, such as Toyota Prius or Lexus RX450h SUV models, which were outfitted with aftermarket equipment, including a large LiDAR (a laser-based ranging system) unit mounted on top of the vehicle.

In May 2014, Google announced that the company would be contracting out the construction of 100 prototype automated vehicles.[23] The prototypes were originally designed without a steering wheel, accelerator, or brake pedals and

[21] Kosoff 2015.
[22] Google 2015.
[23] Urmson 2014.

have a top speed of 25 miles per hour, restricting their use to urban and suburban settings and precluding their use on highways. In addition to Roush, the company that assembled the prototypes, Google indicated that it was working with automotive suppliers Bosch (radar systems and power electronics), ZF Lenksysteme (steering gears); LG Electronics (batteries), and Continental (brakes, tires, body controllers and interior electronics).[24] As of June 2015, Google had only been testing the prototype vehicles on closed tracks, but this summer, Google began test driving prototypes on public roads in California. For initial testing purposes, steering wheels, accelerators, and brake pedals have been added to the prototype vehicles.[25]

APPLE AUTOMATED VEHICLE PROGRAM

Though no tests have been confirmed, and Apple has said little publicly about its efforts to develop an automated vehicle, the company has hired former automaker executives and has reportedly enquired about the use of GoMentum Station, a high-security proving ground for vehicle testing.[26] GoMentum Station is a 2,100-acre former military base in Concord, California (northeast of San Francisco). The facility offers more than 20 miles of paved roads, city streets, railroad crossings and tunnels and has been used by automakers, including Honda and Mercedes-Benz, to test automated vehicle prototypes.

2.4 FLORIDA

Florida hosted the 2011 ITS World Congress, and has continued to push transportation research in the state. In addition to connected vehicle infrastructure deployments (see previous updates), Florida will soon host multiple automated vehicle trials. In addition to the automated vehicle trials already discussed under the US National Level Projects section, Florida will soon construct a closed automated vehicle testing site.

FLORIDA POLYTECHNIC UNIVERSITY TEST CENTER

Similar to the Mcity effort in Michigan, Florida has begun a project to create its own fake town for automated vehicle testing. The site will be just outside Florida Polytechnic University. While the project is currently in the design

[24] Nelson 2015 and Walsh 2015.
[25] Swidey 2015.
[26] Boudette 2015.

phase, when completed, it will be able to simulate both urban and highway driving scenarios and test enhanced tolling and intersection applications.[27]

2.5 VIRGINIA

Virginia has been a leader in CAV testing, with many assets, including the Virginia Smart Road, a 2.2 mile closed-research facility, and the Virginia Connected Test Bed, which was launched in June 2013. The Virginia Tech Transportation Institute (VTTI) and the University of Virginia have both hosted major CAV research projects, including developing equipment and managing data for the Ann Arbor Safety Pilot. More recently, Virginia has been encouraging the automated vehicle research and has created the Virginia Automated Corridor (VAC) to facilitate automated vehicle testing.

VIRGINIA AUTOMATED CORRIDOR

The VAC consists of 70 miles of public roads near Washington, D.C. (See Figure 6), including Interstates 66, 495, and 95; state routes 29 and 50; urban, suburban, and rural roads; and winding mountain lanes, which have been approved for testing automated vehicles.[28] Vehicles will also have access to test tracks including the Virginia Smart Road and the Virginia International Raceway. Researchers seeking to test automated vehicles on the VAC must first have their vehicles approved by Virginia Tech. Currently, the test vehicle must have an occupant (driver) prepared to resume control should problems occur. Test vehicles will have access to high-definition maps, real-time traffic data, intelligent routing services, and hyper-localized positioning systems from Nokia's HERE division (soon to be sold to a consortium of German automakers) as well as V2V communications technologies.[29]

[27] Vlasic 2015.
[28] Simpson 2015a.
[29] Davies 2015.

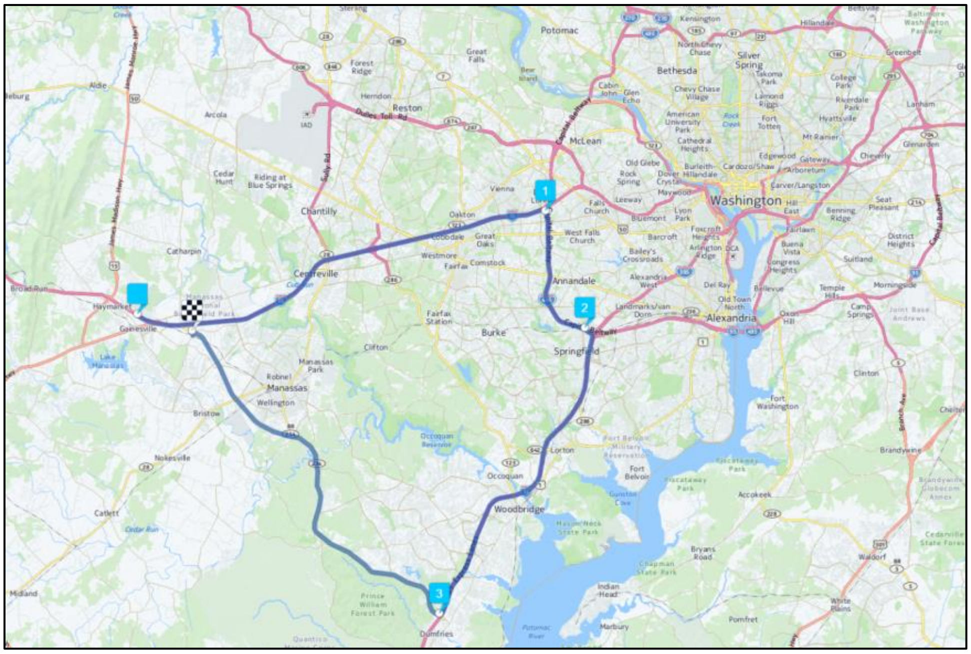

Figure 6: Virginia Automated Corridor

Source: Davies 2015

2.6 PENNSYLVANIA

Pennsylvania is home to Carnegie Mellon University (CMU), which has been heavily involved with CAV development efforts leading back to the initial Defense Advanced Research Projects Agency (DARPA) "Grand Challenge" events held in the mid-2000s. While CMU continues this work, Uber, the transportation network company has begun investing in a nearby research center which will focus on vehicle safety and automated systems.

UBER TESTS IN PITTSBURGH

In February 2015, Uber and CMU announced a strategic partnership to create the Uber Advanced Technologies Center in Pittsburgh, near the CMU campus.[30] In late May 2015, it came out that Uber had hired 40 researchers and scientists from the university to support its efforts.[31] Earlier that month, an experimental Uber vehicle was spotted driving around Pittsburgh. Uber reported that the vehicle was part of an early research effort related to mapping, safety, and automated systems.[32]

[30] CMU 2015a.
[31] Ramsey and MacMillan 2015.
[32] Moon 2015.

GM-CARNEGIE MELLON AUTONOMOUS DRIVING COLLABORATIVE RESEARCH LAB

The GM-Carnegie Mellon Autonomous Driving Collaborative Research Lab (AD-CRL) is focused on the study, design, and implementation of automated vehicle technologies with the aim of making these technologies more practical and affordable. The AD-CRL was created in 2008, shortly after CMU's "Boss" vehicle won the DARPA Urban Challenge.[33]

TECHNOLOGIES FOR SAFE AND EFFICIENT TRANSPORTATION UNIVERSITY TRANSPORTATION CENTER

The Technologies for Safe and Efficient Transportation (TSET) University Transportation Center (UTC) is a collaboration between Carnegie Mellon University and the University of Pennsylvania with funding from the US Department of Transportation. The TSET UTC focuses on research and deployment of transportation technologies in five core areas, including in-vehicle technologies, infrastructure technologies, human-vehicle interactions, mobility/data analytics, and policy.[34]

2.7 IOWA

Though Iowa has not been heavily involved in CAV research in the past, the Iowa Department of Transportation is considering developing a low-speed roadway specifically to encourage testing in the state. Local communities have expressed interest in and support for the idea.

AUTOMATED-VEHICLE-ONLY ROADWAY CONCEPT

The Iowa Department of Transportation is considering the creation of a low-speed roadway from the University of Iowa campus in Iowa City to the North Liberty area. The Iowa City Area Development Group (ICAD) has been attempting to recruit automated vehicle testing to the area, and several local communities, including Coralville, Iowa City, Johnson County, North Liberty, have made resolutions in support of automated vehicle testing. The National Advanced Driving Simulator at the University of Iowa has also been studying

[33] CMU 2015b.
[34] CMU 2015c.

automated vehicles in controlled environments and would likely be involved if the effort materializes.[35]

2.8 TEXAS

Through the Texas A&M Transportation Institute, the University of Texas at Austin, and the US Army, the state of Texas has been involved in research, modeling, development, and testing CAV projects in the past. Recently, Google announced interest in expanding its public road testing to Austin.

GOOGLE TESTS IN AUSTIN

Google is expanding its automated vehicle efforts into new cities. The company expanded testing of its Lexus SUVs to neighborhoods near downtown Austin, Texas. Google is interested in testing its vehicles in a variety of environments, and until now has kept testing in and around Mountain View, California. In order to test its vehicles in Austin, Google received permission from the governor, the Texas Department of Transportation, and the Austin police department.[36]

[35] Morelli 2015.
[36] Simpson 2015b.

3 CAV EFFORTS IN EUROPE

Many of the large connected vehicle research projects in Europe are at least partially funded by the European Commission, national governments, and industry partners. Work on these projects is often characterized by the large consortia with representatives from automakers, suppliers, universities, municipalities, and government agencies.

Figure 7 shows the geographical distribution of projects throughout Europe. Many of the activities associated with these projects are spread across several countries; for mapping purposes, such projects are assigned to the country of their lead coordinator.

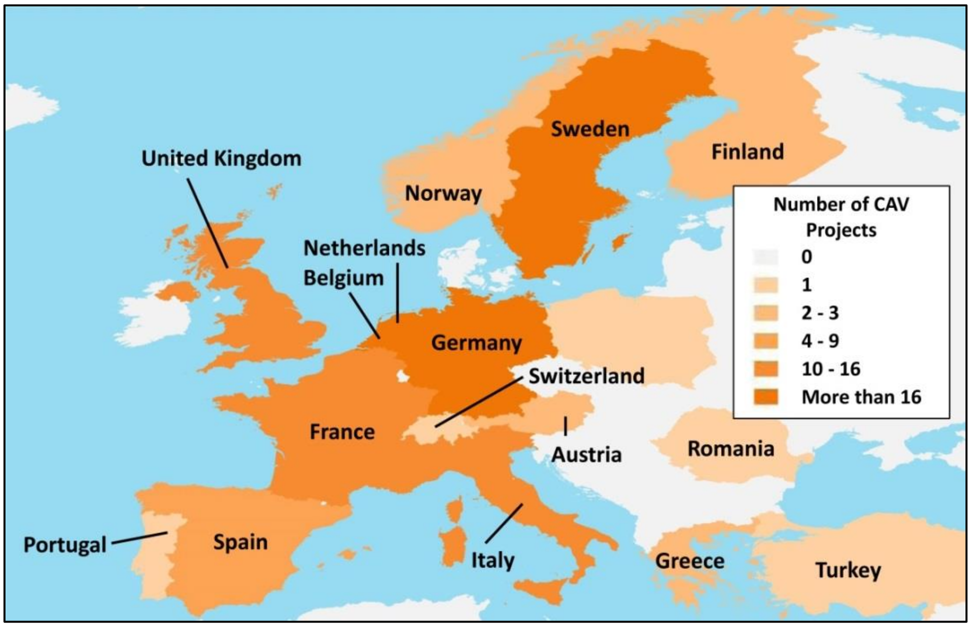

Figure 7: CAV Projects in Europe
Source: CAR 2015

3.1 EUROPE-WIDE PROJECTS

Many of the projects in Europe are funded through the European Commission and coordinated through the European Road Transport Telematics Implementation Co-Ordination Organization (ERTICO-ITS EUROPE). As a result, many of these projects are spread across multiple countries that cooperatively work together.

COOPERATIVE ITS CORRIDOR

In June 2013, the ministries of transport from the Netherlands, Germany, and Austria signed a memorandum of understanding to equip a corridor from

Rotterdam through Frankfurt-Main to Vienna (See Figure 8) with roadside infrastructure required to provide cooperative services to vehicles traveling the route.[37] Service will be offered by the end of 2015. The equipment deployed will utilize DSRC (i.e., 802.11p, 5.9 GHz) and cellular networks (e.g., 3G/4G). The route is the first deployment of a cooperative intelligent transport system between multiple countries and is the result of cooperation between the relevant ministries in each country, highway operators, and automakers.

The system will issue road warning messages and make use of probe vehicle data. Initially, only simple messages, such as work zone warnings, will be issued, using both V2V and V2I communications. Early on, probe vehicle data will be used to improve traffic management through traditional ITS features, such as variable message signs. Later, more elaborate messages will be used, warning drivers of weather conditions or accidents ahead.[38]

In November 2014, the first test drive (named the *Communicating Cars* project) was completed on the Cooperative ITS Corridor. The test drive involved a convoy of five Honda vehicles that drove along 1,300 kilometers (800 miles) of roads in the corridor (including test beds in Munich, Vienna, and Helmond). The test drive required the collaboration of several organizations including NXP, Siemens, Honda, Cohda Wireless, TÜV Süd, automobile clubs AvD and ANWB, and various government representatives.[39]

---

[37] BMVBS 2013.
[38] Cooperative ITS Corridor 2015.
[39] Kable 2014.

Figure 8: Cooperative ITS Corridor Connecting Rotterdam, Frankfurt/M., and Vienna

Source: Cooperative ITS Corridor 2015

FOT-NET DATA

In order to aggregate information on various field operational tests (FOTs) and make that information publicly available in one location, the European Commission created the FOT-Net and FOT-Net 2 projects, which lasted from 2008 through 2014. The FOT-Net Data project is a follow-on project which focuses on efficiently sharing and reusing data from FOTs.[40] Sharing and reusing data from recently completed FOTs can further research goals, create new collaborative opportunities, and save resources (i.e., time and money). FOT-Net Data has held several events since it began in 2014, including a workshop on data reuse at the 2014 ITS World Congress in Detroit. In addition to working with stakeholders to promote sharing and reuse of data, FOT-Net Data continues the networking function of the FOT-Net project and maintains the FOT Wiki.[41] The FOT-Net Data project is being funded through the European Commission 7th Framework Programme and will run through December 2016.

[40] ERTICO 2015.
[41] FOT-Net 2015.

FEASIBILITY ANALYSIS AND DEVELOPMENT OF ON-ROAD CHARGING SOLUTIONS FOR FUTURE ELECTRIC VEHICLES

The *Feasibility Analysis and Development of On-Road Charging Solutions for Future Electric Vehicles* (FABRIC) project seeks to conduct feasibility analysis of on-road induction charging technologies for electric vehicles. The project uses vehicle communications to enable on-road charging. The test sites are spread across multiple countries, including France, Italy, and Sweden. The FABRIC project began in January 2014 and will continue through December 2017. It is supported and co-funded by the European Union Seventh Framework Programme, the European Council for Automotive R&D (EUCAR) and ERTICO-ITS Europe. The project budget is €9.0 million, with a European Union contribution of €6.5 million.[42]

VEHICLE AND ROAD AUTOMATION

The *Vehicle and Road Automation* (VRA) project is a support action that began in July 2013 to create a collaborative network of experts and stakeholders dedicated to facilitating deployment of automated vehicles and infrastructure. VRA links together stakeholders in several different projects and activities that have been funded through the European Commission. The project considers possible deployment scenarios, legal and regulatory issues, and future standards. The VRA project has a budget of €1,685,000 (€1,319,000 from the European Commission 7th Framework Programme) and is planned to continue through December 2016.[43]

JOINT EUROPEAN PROJECT FOR INTERNATIONAL ITS/EGNSS AWARENESS RAISING

The European Global Navigation Satellite Systems (EGNSS) is a European Union agency satellite navigation program. The Joint European Project for International ITS/EGNSS Awareness Raising (Jupiter) project was created to increase awareness and facilitate adoption of the EGNSS for transportation. Jupiter promotes companies developing ITS applications related to EGNSS, such as traffic and parking space management, electronic tolling, advanced driver assistance, fleet management, insurance, and automated driving. The project is coordinated by Aerospace Valley and other consortium partners

[42] FABRIC 2015.
[43] VRA 2015.

include ERTICO-ITS EUROPE, TOPOS (an "excellence cluster" in France), the Czech Republic Ministry of Transport, Pildo Consulting SL, Istituto Superiore Mario Boella, Capital High Tech, Thales Alenia Space France, Telespazio France, and GNSS Usage Innovation & Development of Excellence. The project is funded by the European Commission under the Horizon 2020 Space Program, and it will run from January 2015 through December 2016.[44]

OPTICITIES

The goal of the OPTICITIES project is to develop and test ITS solutions utilizing real-time traffic information to improve urban mobility (traffic conditions and logistics operations). The project has 25 partners across Europe and six pilot cities that are implementing new technologies to collect and use data real-time. These pilot cities include Lyon, France; Madrid, Spain; Torino, Italy; Gothenburg, Sweden; Birmingham, United Kingdom; and Wroclaw, Poland. OPTICITIES has a budget of €13 million and is co-funded by the European Commission through the European Commission 7th Framework Program. It began in November 2013 and will continue through November 2016.[45]

Cooperative Mobility Pilot on Safety and Sustainability Services for Deployment

The *Cooperative Mobility Pilot on Safety and Sustainability Services for Deployment* (Compass4D) project (January 2013-December 2015) focuses on improving safety, energy efficiency, and congestion. The project includes deployments in the cities of Bordeaux, France; Copenhagen, Denmark; Helmond, Netherlands; Newcastle, United Kingdom; Thessaloniki, Greece; Verona, Italy; and Vigo, Spain. In addition to installing roadside infrastructure, the project has developed business models, cost-benefit analysis, and exploitation plans. The final event for Compass4D will be held in October 2015 during the ITS World Congress in Bordeaux.[46]

[44] Jupiter 2015.
[45] OPTICITIES 2015.
[46] Compass4D 2015.

3.2 GERMANY

Germany has hosted more CAV projects throughout the years than any other European country. Germany is currently hosting the *Automated Driving Applications & Technologies for Intelligent Vehicles* (ADAPTIVE) project and recently completed the *Safe and Intelligent Mobility Test* Germany (sim^{TD}). The country is also currently developing its portion of the *ITS Cooperative Corridor* and beginning a project called ANIKA.

PROJECT ANIKA

The idea for the *ANIKA* project is that existing emergency telephone infrastructure could be upgraded with wireless ITS capabilities. The telephone sites can pass information to passing vehicles notifying them of road conditions and critical situations on the road ahead, putting drivers on alert and reducing accidents. There are 16,000 currently operating emergency telephones in Germany, and the project could scale to beyond Germany, as similar emergency telephones are also available in other European countries. Emergency telephones are landmarks and georeferenced location information for them already exists.[47] This project is relatively new and publicly-available information on its budget and current state of development is somewhat limited as of the publication of this document.

3.3 NETHERLANDS

The Netherlands have hosted numerous CAV projects throughout the years. Most of the major projects in the Netherlands have been connected vehicle projects, but the country is working to develop automated vehicle projects as well. The country is modifying its laws to permit public road testing of automated vehicles and is already conducting demonstrations.

AUTOMATED VEHICLE ROAD TESTS

Lawmakers in the Netherlands have been reviewing traffic laws and considering revisions to permit large-scale testing automated driving technology on public roads since at least June 2014.[48] In January 2015, those lawmakers agreed to revised regulations to allow automakers to conduct large-

[47] ITS Germany 2015.
[48] Auto News 2014.

scale tests of automated vehicles on public roads.[49] The decision to allow more tests on public roads was made following an automated car demonstration in November on the A10 highway outside of Amsterdam. In February, Scania conducted a follow-up demonstration using automated trucks. Aside from those two public demonstrations, automated vehicle research in the Netherlands had been largely been confined to private, closed tracks due to traffic regulations.[50]

TRUCK PLATOONING

In early 2015, Scania conducted a test drive of a truck platooning application on the A28 in the Netherlands. The platoon involved three Scania R500 Streamline trucks. All trucks had drivers to steer the vehicles, but the acceleration and braking in the following trucks was controlled by lead truck using wireless communications. Platooning allows vehicles to drive closer together, improving aerodynamics and reducing fuel consumption. The test indicated that by reducing the gap between vehicles to two seconds, the vehicles used five percent less fuel. In addition to improving truck fuel economy, platooning can provide positive externalities to other road users by reducing congestion. In the future, Scania plans to produce and test fully-automated vehicles.[51]

3.4 SWEDEN

As with Europe in general (demonstrated by ERTICO), Sweden has taken a strong policy stand on automotive safety. Most notably, in 1997, Sweden initiated a governmental program called *Vision Zero* which is intended to eliminate traffic-related deaths and incapacitating crashes.[52] Sweden has been an early and active participant in CAV testing and deployment activities, hosting several different projects throughout the years. Recently, the largest projects in Sweden have been *Drive Me*, a deployment of automated vehicles, and the *AstaZero Proving Ground*, a closed test facility for vehicle safety technologies.

[49] DITCM 2015.
[50] CTV 2015.
[51] ITS International 2015a.
[52] Whitelegg and Haq 2006.

DRIVE ME

In spring 2014, Volvo announced its *Drive Me* pilot project, which will ultimately have 100 highly-automated Volvo XC90 crossovers driving alongside regular traffic on 50 kilometers (31 miles) of public roads in and around the city of Gothenburg, Sweden.[53] The public roads open for the automated vehicle pilot testing will contain barriers between lanes. As of 2015, the project in the customer research and technology development phase. The full-scale test with ordinary drivers in a real traffic environment will begin in 2017 and run through spring 2019.[54]

At the current stage of the project, test vehicles are equipped with technology to automate lane keeping, speed adaptation, and merging into traffic. These applications are made possible using hardware already available in some of Volvo's production vehicles, such as the cameras and sensors required for Volvo's City Safety and Pedestrian Detection driver-assistance features.[55] The 2016 Volvo XC90 is already equipped with some of the systems (e.g., three radar systems and four cameras) and much of the equipment and algorithms will be reused for the pilot vehicles. The automated system for the pilot will prompt drivers to resume control of the vehicle in the event of inclement weather, technical malfunction, or upon reaching the end of a route. In the event of an incapacitated driver, the vehicle will automatically drive to a safe place and stop.[56]

Project stakeholders include Volvo Car Group, the city government of Gothenburg, legislators, transportation authorities (including the Swedish Transport Administration and the Swedish Transport Agency), and Lindholmen Science Park.[57] The customers/test drivers will lease and drive the 100 test vehicles, but will not pay for the full cost of the technology in their vehicles.[58]

ASTAZERO PROVING GROUND

In August 2014 Volvo, in partnership with, Scania, Autoliv, and *Test Site Sweden*, opened its new $72 million AstaZero proving ground near

[53] Volvo 2014.
[54] Kurylko 2015.
[55] Newcomb 2014.
[56] Kurylko 2015.
[57] Volvo 2014a.
[58] Kurylko 2015.

Gothenburg, Sweden. Volvo, along with its industry and university partners, will use the AstaZero site to conduct vehicle research and innovation projects related to a range of traffic solutions, including automated vehicle technology. The site will be an open, international platform for interested stakeholders, including automakers, suppliers, legislators, road agencies, universities, and technical institutes.[59]

The AstaZero site itself has a total surface area of approximately 2,000,000 square meters (21.5 million square feet) and a paved surface of 250,000 square meters (2.7 million square feet).[60] The proving ground is surrounded by a 5.7 kilometer (3.5 mile) highway and contains a 700 meter acceleration track.[61] Test environments include rural roads, city areas, multilane roads, and a high-speed area.

Since opening, AstaZero has been used to conduct trials for both Volvo Cars and Volvo Trucks. The two entities have recently been partnering at AstaZero for the *Non-Hit Car and Truck* project. The project uses cameras and radar sensors to detect cyclists and pedestrians. The vehicle can use this information to automatically apply the brake to avoid collision.

3.5 UNITED KINGDOM

The United Kingdom has not traditionally been a major participant in much of the CAV activities in Continental Europe, and therefore, has not been well documented in past updated of this document. In the past year, the United Kingdom completed its regulatory review and has pushed forward development of its automated vehicle trials, which have been prominently featured in the media.

REGULATORY REVIEW

In 2014, the United Kingdom government announced that automated vehicles will be allowed to drive on public roads beginning in January 2015. Ministers ordered a review of road regulations to provide appropriate guidelines for automated vehicles, address the need for automated vehicles to comply with existing laws, and identify areas where the laws must be changed.[62] The

[59] Volvo 2014b.
[60] Volvo 2014b.
[61] Volvo Trucks 2015.
[62] BBC 2014.

review will include revisions to the Highway Code and will likely add a section on automated vehicle technologies. The changes will clarify liability for automated vehicle collisions.[63]

DRIVERLESS VEHICLE TRIALS

Along with the 2014 announcement that the United Kingdom would soon allow automated vehicles on its public roads, the government also announced plans to conduct three automated vehicle trials. It solicited applications from partnerships composed of cities, private business, and research organizations.[64] Applications to host an automated vehicle trial were due by October 2014, and selected proposals were awarded a share of a £19 million ($29.2 million) fund allocated for the trials.[65] The selected projects began in early 2015 and are expected to last for 18-36 months.[66]

The first of the trials, Greenwich Automated Transport Environment (GATEway) project, began in February 2015 and is located in Greenwich, London. The project is using the Meridian Shuttle, an automated vehicle which will undergo testing over a two-year period. The tests will involve multiple scenarios, and evaluation will include many important factors. In addition to providing an automated vehicle demonstration, the pilot will help evaluators better understand legal and technical challenges, as well as reactions from other road users, such as pedestrians and drivers. The partnership hosting the trial is composed of eleven members, including the Transport Research Laboratory (an independent transport consultancy and research company), the Royal Borough of Greenwich, RSA (a global insurance group), Royal Dutch Shell (a multinational oil and gas company), Telefonica (a telecommunications provider), and the University of Greenwich.[67]

Another project, UK Autodrive, was also one of the three selected pilots in the competition. It will take place in the communities of Milton Keynes and Coventry.[68] The vehicle to be tested is the Lutz Pathfinder pod (See Figure 9), which is a two-seated, electric-powered vehicle outfitted with sensor and navigation equipment from the Mobile Robotics Group at the University of

[63] ITS International 2015b.
[64] Mozée 2014.
[65] Wakefield 2015.
[66] BBC 2014.
[67] ITS International 2015b.
[68] ITS International 2015b.

Oxford.[69] The vehicle is approximately nine feet long and has a 40-mile driving range.[70] Partners include Arup, Milton Keynes Council, Coventry City Council, Jaguar Land Rover, Ford Motor Company, Tata Motors European Technical Centre, RDM Group (an advanced engineering company), MIRA (formerly the Motor Industry Research Association), Oxbotica (a tech company spin-out of Oxford University's Mobile Robotics Group), AXA (an insurance group), Wragge Lawrence Graham & Co. (an international law firm), the Transport Systems Catapult (an Innovate UK technology and innovation center that focuses on intelligent mobility), University of Oxford, University of Cambridge, and Open University.[71] The partners are matching the government funds, resulting in a project budget of £19.2 million ($29.5 million).[72]

Figure 9: One of the Prototype Tested in the Milton Keynes Deployment

Source: Scott 2015

The third project, the VENTURER consortium, will be hosted in Bristol. The project focus will be public acceptance, legal issues, and insurance implications associated with automated driving technology.[73] Partners include Atkins Global (a design, engineering and project management consultancy),

---

[69] TS Catapult 2015.
[70] Scott 2015.
[71] Wakefield 2015.
[72] Schofield 2014.
[73] Wakefield 2015.

Bristol City Council, South Gloucestershire Council, AXA, Williams Advanced Engineering (a technology and engineering services firm), Fusion Processing (an electronic safety systems firm), Centre for Transport and Society at the University of the West of England, University of Bristol, and Bristol Robotics Laboratory (a multi-university collaborative lab).[74]

UNIVERSITY PARTICIPATION

Each of the three major UK deployment projects involves university participation, but even before the driverless vehicle trials were announced, universities were conducting research into automated vehicles. The University of Oxford has been particularly involved with work in this area and tested a "Robot Car" prototype (a modified Nissan LEAF) at Begbroke Science Park in February 2014.[75] Until the last year, the Oxford prototype was the only automated vehicle in the UK with permission for public road testing. Automated driving technology developed at Oxford is being used in the Lutz Pathfinder pods for the driverless vehicle trials. In addition to the national trials, testing of the Robot Car prototype continues, and the University of Oxford has released videos of those tests.[76]

Several UK universities have committed to an £11 million ($16.6 million) project to coordinate work on automated vehicles. Currently much of the testing is on a driving simulator, but eventually, the studies will progress to the test track and ultimately, to public roads.[77]

JAGUAR LAND ROVER POTHOLE DETECTION

In Coventry, Jaguar Land Rover is testing vehicle technology that will use vehicle sensors and cameras to collect road condition data, identify potholes, damaged manhole covers, and broken drains. The vehicle will then use connected vehicle technology to report these features to other vehicles and authorities in charge of maintaining road infrastructure. The research team is working with the Coventry City Council to understand how the collected information could be shared with and used by road authorities.[78]

[74] Bristol 2014.
[75] Wilton 2015.
[76] Wilton 2015.
[77] Southampton 2015.
[78] Jaguar Land Rover 2015.

4 CAV EFFORTS IN ASIA

Japan has been the home for the majority of connected vehicle research and infrastructure deployment in Asian, and a significant portion of the work in Japan has been done at the national level. Once nationally funded infrastructure has been deployed, industry partners have tested and released technologies that can interact with the infrastructure. Many of the companies involved in these projects gained experience in CAV technologies and commercialized products. In many cases, those companies have applied their knowledge to aiding research and deployment efforts in other countries, both inside and outside of Asia.

Figure 10 shows the geographical distribution of projects in Asia. For discussion of projects occurring in the Middle East, Oceania, and the rest of the world, see Section 5.

Figure 10: CAV Projects in Asia
Source: CAR 2015

4.1 JAPAN

Japan has a long history of ITS and CAV technology beginning in the 1970s. Electronic toll collection (ETC) service quickly became ubiquitous after its introduction in 2001. From 2007-2010, the Japanese government partnered with industry to support activities to promote the Driving Safety Support Systems (DSSS), Advanced Safety Vehicle (ASV), and Smartway systems, each of which use CAV technology to improve safety and mobility. In 2011, Japan began offering ITS Spot (5.8 GHz wireless band DSRC) services (i.e., dynamic route guidance and safety applications) nationwide. More recently, Japan combined its ETC and ITS Spot services. Japanese companies are continuing to innovate in CAV technologies and the Japanese government is working to help coordinate CAV related industry standardization.

ELECTRONIC TOLL COLLECTION 2.0 AND ITS SPOT SERVICE

By 2014, 90 percent of all toll transactions were conducted using ETC.[79] In fall 2014, the Japanese government introduced ETC 2.0, which provides conventional ETS service along with new route-based service (i.e., incentives to use less-congested routes) and ITS Spot services.[80] The service makes use of the existing ITS Spot infrastructure (which is deployed at 1,600 locations). ETC 2.0 service began in August 2015 and current adoption levels are low. The ETC 2.0 device for vehicles costs approximately ¥36,870 ($300), compared to the previous ETC device which cost a fifth as much. In order to increase adoption of ETC 2.0 devices, the Japanese government is considering offering subsidies in 2016.[81]

JAPANESE STANDARDIZATION EFFORTS

In 2015, the Japanese government created a project to promote standardization of parts, components, and system architectures required for CAV technologies. The project involve collaboration between Japanese transportation officials, automakers (e.g., Toyota, Honda, and Nissan), suppliers (e.g., Denso, Panasonic, and Hitachi), and research institutes (e.g., University of Tokyo and Nagoya University). The collaboration is geared towards establishing common global hardware and software specifications as well as safety regulations. The Japanese government and Japanese automakers are committing an investment of ¥10 billion ($83.4 million) for the construction of test roads for these technologies.[82]

DENSO AUTOMATED VEHICLE TESTING

In June 2015, Denso began testing automated vehicle technology on public roads in the Aichi Prefecture (see Figure 11). The company is conducting tests involving automated driving functions in a single lane, automated lane

[79] Cregger 2014.
[80] Yamamoto 2014.
[81] Shimoyama and Minetoshi 2015.
[82] Young 2015.

changing, and other driving maneuvers. Denso conducted previous tests on a closed course in Japan. Testing on public roads represents the next step in development for this technology. Denso is conducting its field tests in cooperation with the Aichi prefectural government.[83]

Figure 11: Denso Automated Test Vehicle Driving on a Public Road

Source: Denso 2014

TOYOTA CONNECTED VEHICLE TECHNOLOGY DEPARTMENT

In March 2015, Toyota announced that it is going to create a department to unify its expertise in connected vehicle technologies. The new Connected Strategy and Planning Department will direct Toyota's strategy on connected vehicles as well as explore collaborative opportunities in related fields, including automated vehicles and advanced driving assistance systems.[84]

4.2 CHINA

Though mainland China has lagged behind Japan and Taiwan in terms of CAV research and deployment efforts, it is rapidly catching up. Chinese technology companies such as Baidu and Alibaba are collaborating with more

[83] Denso 2014.

[84] Kubota 2015.

established automakers to develop automated vehicles. These collaborations are in addition to several other projects discussed in previous updates.

BAIDU AND BMW AUTOMATED VEHICLE EFFORTS

In June 2015 at the China Cloud Computing conference, Baidu (a large web services firm in China) announced that it would release its first automated vehicle before the end of the year.[85] Baidu has announced that it is working with BMW to build the vehicle. Baidu announced its interest in automated vehicles April 2014, and has been pursuing the project ever since. The company has driven test vehicles on the highways surrounding Beijing and Shanghai. Compared to Google, Baidu's automated driving system is more traditional, and the vehicle will retain its steering wheel, accelerator, and brake pedal.[86]

ALIBABA AND SAIC CONNECTED VEHICLE EFFORTS

Shortly after Baidu's announcement, Alibaba, China's biggest tech company, announced that it is partnering with China's largest automaker, SAIC Motor Corporation, to create a connected vehicle capable of V2V communications.[87] The connected vehicle would improve the driving experience through features such as e-commerce, digital entertainment, mapping, and communications services. The ¥1.0 billion ($160 million) joint venture could result in a vehicle as early as 2016.[88]

4.3 SINGAPORE

Singapore has long invested in ITS, and has used a variety of technologies for traffic analysis and planning, traffic monitoring, incident management, parking guidance, and route guidance. Recently, Singapore has designated an area, the "One-North" district, for automated vehicle testing. In the past few years, Singapore has been host to new partnerships to test CAV technologies, such as the Singapore-Massachusetts Institute of Technology (MIT) Alliance for Research and Technology (SMART).

---

[85] BBC 2015a.
[86] Gibbs 2015.
[87] Ross 2015.
[88] DW 2015.

SINGAPORE AUTONOMOUS VEHICLE INITIATIVE

Since August 2014, the Singapore Land Transport Authority (LTA), has been collaborating with the Agency for Science, Technology and Research (A*STAR) on the Singapore Autonomous Vehicle Initiative (SAVI), a project to manage automated vehicle-related R&D. Part of this project is the creation of an automated vehicle test bed in Singapore's "One-North" district, which a 500 acre development designed to host high-tech research, engineering, and business facilities. LTA has been working closely with the JTC Corporation, the master planner and developer of the One-North district, to identify a nearly four-mile network of test routes (see Figure 12) connecting various neighborhoods in the district (Biopolis, Fusionopolis, and Mediapolis). LTA is currently accepting applications from research groups interested in automated vehicle testing.[89]

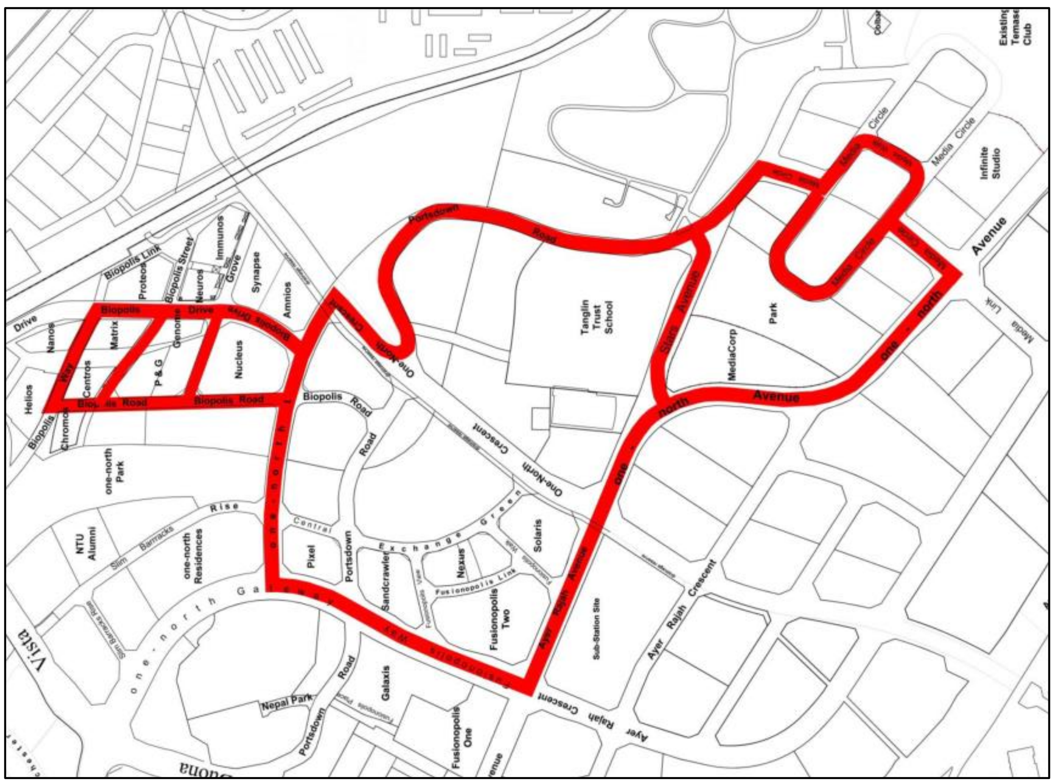

Figure 12: One-North Automated Vehicle Test Bed

Source: Land Transport Authority 2015

[89] LTA 2015.

SINGAPORE-MIT ALLIANCE FOR RESEARCH AND TECHNOLOGY

SMART is working to develop an automated vehicle that will operate on public roads. The project is a collaboration between MIT and the National University of Singapore (NUS) on this deployment project. The project is focused on small trips and will promote car-sharing (i.e., automated taxi).[90]

The Singapore team has developed an automated vehicle prototype named *Shared Computer Operated Transport* (SCOT),[91] which costs S$30,000 ($23,500). SCOT is a Mitsubishi iMiev electric car that that uses two off-the-shelf LiDAR sensors and an onboard computer. The vehicle uses finely detailed camera- and lidar-based localization technology to determine the vehicle’s location and its surroundings around it. The approach requires constructing detailed maps beforehand using the sensors and a manually driven vehicle.[92] SCOT can sense obstacles and operates well in poor lighting and moderate rain. The project team hope to eventually bring the cost down to S$10,000 ($7,800).[93]

During an early test in 2011, NUS and SMART ran an automated golf cart through a closed course on the NUS campus.[94] In fall 2014, the research team ran a six-day trial at Singapore’s Chinese and Japanese Gardens. Participants used an online system to book trips between 10 “stations” scattered around the gardens. Over the period of the trial, the vehicles provided more than 200 rides to visitors.[95]

While most of the tests have been conducted on campus roads or other closed courses, in coming months, the research team expects to receive government permissions to expand its test drives to the automated vehicle testbed in Singapore’s One-North district. Those test drives will allow vehicles to experience real-world conditions and interact with conventional traffic on public roads.[96]

---

[90] SMART 2014.
[91] Manibo 2014.
[92] Swidey 2015.
[93] Lee 2014.
[94] Lee 2014.
[95] Swidey 2015.
[96] Swidey 2015.

4.4 TAIWAN

Taiwan is home to several organizations that are advancing vehicle and technology research, most notably the Automotive Research and Testing Center (ARTC), which has several CAV-related initiatives, primarily revolving around safety.[97] The ARTC hosted Taiwan's first automated vehicle demonstration in Taiwan in May 2015, which was conducted by a team from National Taiwan University (NTU).[98] The Industrial Technology Research Institute (ITRI) of Taiwan is another organization that is researching cutting edge connected vehicle technology. ITRI's products have been used in a several CAV trials around the world. In 2015, ITRI debuted several new robotic devices, including automated vehicle technology.[99]

[97] ARTC 2015.
[98] NTU 2015.
[99] ITRI 2015.

5 CAV EFFORTS IN OTHER REGIONS

Though the majority of CAV projects are based in North America, Europe, and Asia, other regions are also beginning to consider projects. Much of the work in these other regions is driven by individual companies, though some governments are beginning to develop their own initiatives. In particular, Australia, which has long monitored activities in other regions, will soon launch its own automated vehicle tests on public roads. Several countries in the Middle East, Africa, and South America are developing more traditional ITS systems, are not heavily involved in major CAV projects.

5.1 OCEANIA

Over the past several years, Australia has closely monitored CAV developments in North America, Europe, and Asia. It has secured the DSRC bandwidth for ITS and conducted some connected vehicle trials. Cohda Wireless, a technology company providing communications equipment for several of the major connected vehicle projects throughout the world, has been involved and pushed for tests in Australia. In the past few years, Australia and New Zealand have been considering automated driving trials.

AUSTRALIAN DRIVERLESS VEHICLE INITIATIVE

Australia's first automated vehicle demonstration trials will be held in 2015 from November 7th to 8th in and around Adelaide, the state capital of South Australia. The vehicles will be tested on the Southern Expressway, at the Adelaide Airport, and at the Tonsley Innovation Park.[100] The tests will involve multiple vehicles conducting various maneuvers, including overtaking, lane changing, emergency braking, and using on- and off-ramps. The project is managed by the ARRB Group, Australia's national independent road research agency. Volvo Car Australia is providing vehicles for the test (Volvo XC90) modified to allow hands-free use of IntelliSafe Assist features (including adaptive cruise control, pilot assist, lane-keeping, distance alert and speed-limiter functions). Other partners include Carnegie Mellon University, Cohda Wireless, Flinders University, and the Royal Automobile Association of South Australia.[101]

[100] ABC 2015.
[101] Harman 2015.

New South Wales Initiative

The New South Wales Centre for Road Safety began its five-year Cooperative Intelligent Transport Initiative (CITI) trial in June 2014. Cohda Wireless is providing 5.9 GHz devices for the trial.[102] The test facility is located south of Sydney, and it is dedicated to testing connected vehicle technology for heavy-duty vehicles. There are currently 60 vehicles with in-vehicle communication units installed. Infrastructure includes a roadside transmission station to broadcast speed limit information and three intersections broadcasting signal phase and timing (SPaT) information.[103]

CANBERRA AUTONOMOUS CAR SIMULATION

The Canberra Autonomous Car Simulation tool can be used to analyze the use of automated vehicles on the streets of Canberra.[104] The model also allows users to explore the use of electric vehicles and to look at costs and wait times for automated vehicles.

NEW ZEALAND AUTOMATED VEHICLE ROAD TESTS

Transportation officials in New Zealand have met with companies, including Google and Nissan Motor Company to discuss testing automated vehicles on public roads. No legislative changes are required to conduct testing in New Zealand, but policymakers are examining other related issues. For instance, one key question is how to assign legal liability in the event of a traffic offence or collision.[105]

5.2 MIDDLE EAST

Israel has been the most active country for CAV work in the Middle East. The country's ITS roadmap goes out to 2020 and considers adoption of V2V, V2I, and eCall (a European in-vehicle emergency communication service) technologies.[106] Israel has conducted work on machine vision and the Israeli military has been using CAV technologies for several years.[107] The country is home to companies such as MobilEye and G-NIUS Unmanned Ground

102 Barwick 2014.
103 NSW 2015.
104 Fitch 2015.
105 Bradley 2015.
106 ITS International 2013.
107 Main 2013.

Systems Ltd. The strong military manufacturing base in Israel could be leveraged for civilian CAV projects.

The United Arab Emirates (UAE) is also a focal point for CAV deployment in the Middle East. Etisalat (a UAE telecommunications provider) and Nissan partnered to launch the "Nissan SmartCar" mobile application during the 2015 Dubai International Motor Show. The two partners will work together to "deliver scalable, secure, interoperable and intuitive connected experiences to customers." The new application will be available in the 2016 Nissan Maxima and Nissan Patrol.[108] In Dubai,

UAE's Roads and Transport Authority (RTA) has been working to implement smarter solutions, including mobile applications to provide users with real-time information on bus location and timing, road construction and repair, car parking management, and waste collection. RTA has also installed 100 smart air-conditioned bus shelters with internet connectivity and other services.[109] The UAE's Masdar project incorporates automated electric vehicles in its pilot personal rapid transit system.

Qatar has a mobility innovations center conducting CAV research,[110] and a Qatar-based company, Masarak is also developing CAV services (i.e., traffic monitoring using Bluetooth devices in passing vehicles).[111] Several other countries in the Middle East are developing more traditional ITS systems, but few are leading major CAV deployment efforts.

5.3 AFRICA

Projects in Africa are limited to mobile phone applications, such as GoMyWay, a ride-sharing app in Nigeria that will soon be launched in Kenya, Ghana, and South Africa, as well.[112] Though South Africa has been discussed as relatively advanced in terms of ITS within Africa,[113] the South African government has not taken action to facilitate automated testing or deployment in the country.[114]

---

[108] MENA Herald 2015.
[109] Emirates 24/7 2015.
[110] QMIC 2015.
[111] Masarak 2015.
[112] GoMyWay 2015.
[113] ITS South Africa 2015.
[114] Emma-Iwuoha 2015.

5.4 SOUTH AMERICA

In South America, CAV work is mostly limited to university research, though driverless mining vehicles have been used in Chile for more than a decade.[115] Much of the university work is being done in Brazil. The University of São Paulo conducted Brazil's first automated vehicle test on public roads in the city of São Carlos. Two other universities in Brazil, the Federal University of Espírito Santo and the Federal University of Minas Gerais are also conducting automated vehicle work.[116]

[115] Habibovic 2014.
[116] Oliveira 2013.

6 CONCLUSIONS AND RECOMMENDATIONS

Various regions throughout the world are exploring CAV technologies, and there have been several different approaches to developing these technologies. Research, demonstration, and deployment projects, in particular those in the United States, Europe, and Japan, have demonstrated the potential of CAVs to improve transportation systems. In the United States, the focus is primarily on safety research. While some states currently have roadside infrastructure deployed, this is largely for research and demonstration purposes. Infrastructure may become more practical as more cities install infrastructure under the expanded USDOT *Connected Vehicle Pilot* program and automakers introduce DSRC equipped vehicles in the next few years.

Europe has a similar research-based approach, emphasizing safety and efficiency. In Europe, however, projects have been significantly more top-down and have involved large coalitions of countries, industry partners, and universities. With the introduction of the Cooperative ITS Corridor, normal drivers in Europe may begin benefitting from DSRC services.

In terms of infrastructure deployment, Japan is far ahead and continues to evolve its system. The country already has deployed a connected vehicle system that uses mobile phone technology, DSRC, and IR and has a significant user base due to its ubiquitous ETC system.

Much of the automated vehicle projects are still being tested in closed facilities, through public road tests are being approved across the world. Most of these deployments are often limited to a single campus or a small neighborhood. As more countries and states revise rules on the use of automated vehicles on public roads, these projects will expand their geographic scope.

Despite regional differences in CAV programs, there are many useful overarching themes to consider with respect to technology deployment. The following subsections discuss potential funding strategies that have been used to support CAV programs, important factors that can affect the success of deployment, and considerations for research, development, and deployment of CAV technologies.

6.1 PROJECT FUNDING STRATEGIES

CAR’s review of CAV, ITS, and related activities, both domestically and abroad, has revealed at least four distinct, but successful, strategies for funding such activities. The widespread use of these approaches (matching funds, national or international grants, toll or fee-based systems, and private industry financing) reinforces the need for adequate and additional funding streams to allow a state or country to lead in the area of CAV and ITS technologies.

COMMITTING BUDGET ALLOCATIONS REQUIRING MATCHING FUNDS

This method of leveraging initial funds to attract additional investment from other private and public sources is extremely common at the national level and is not limited to the United States. For example, several of the European projects that received funding through the European Commission also had to obtain funding from industry. Similarly, in the United States, the USDOT typically requires some level of matching funds or in-kind contribution for funded projects. In Michigan, large projects, such as the Connected Vehicle Environment, leverage federal, state, and industry contributions.

PURSUING FUNDING AT THE NATIONAL OR INTERNATIONAL LEVEL

Beyond the first approach listed, top CAV research and deployment states, such as Michigan, California, and Virginia have actively pursued federal dollars. In Europe, projects in several countries are primarily supported through European Commission funding. In Germany, the state of Hessen has leveraged its experience and existing assets to secure funding for new projects from the German national government.

USING TOLLS TO FUND PROGRAMS

Though most of the ITS technologies used in tolling are not technically CAV applications, there are several examples in the United States and elsewhere of using toll revenues to provide funding for innovative solutions. Electronic tolling was an early application of the Japan’s ITS program, and it continues to be central in the evolution of CAV technology deployment in Japan.

CONDUCTING PRIVATE COMPANY-DIRECTED RESEARCH

Major automakers and several suppliers have been involved in CAV research, development, and testing. While in some cases, such work has been part of a larger effort, which may draw on outside resources, other times it has been internally funded and conducted within company labs or on company test tracks. Google’s automated vehicle deployment is an example of a private project that is internally-funded, and Google may soon be joined by other large tech companies, such as Alibaba, Apple, and Baidu. Efforts to create open public test beds represent public efforts to help facilitate more private deployment testing. Across the world, several firms are partnering with a single university or research institute to develop CAV technologies rather than depending on a larger coalition or major national initiative.

6.2 IMPORTANT FACTORS SHAPING PROJECT SUCCESS

In CAR's review of CAV and related activities, several important factors influencing project success emerged pertaining to the research, development, and deployment of CAV and other ITS technologies.

FORMING COALITIONS

Compared to projects in the United States, successful projects in Europe tended to be backed by larger coalitions. European projects tended to have significant participation from transportation agencies, communities, universities, research institutions, and private industry. These public-private partnerships have been instrumental to successful tests and deployment, often driven by a common goal of enhanced vehicle safety. On the other hand, partnerships for Asian projects were smaller and often similar to the size of American project partnerships, but tended to center around national government agencies and manufacturers whereas American partnerships are more frequently focused on universities and state agencies. These differences may reflect differences in funding mechanisms, governance, or stage in research and development for CAV programs across regions.

FACILITATING INDUSTRY COMPETITION

An approach used by Japan, one of the most advanced countries in ITS and CAV deployment, is to set standards and create infrastructure test deployments and invite manufacturers to participate in field tests. This was done for the DSSS, ASV, and *Smartway* projects. By using such a method, Japan has driven its manufacturers to create and test systems meeting the criteria of these three projects. Several vehicle manufacturers and suppliers developed products and participated in tests for these systems.

DEVELOPING PROGRAMMATIC THEMES AND BOLD GOALS

Internationally, having a strong programmatic theme was particularly useful in moving projects and deployments forward. Around the world, the major theme for CAV technologies is centered around safety and crash prevention.

Safety is a particularly strong theme in Europe, as demonstrated in Sweden's *Vision Zero*, a goal to eliminate traffic fatalities, which has facilitated many CAV projects in Sweden. In North America, convenience features are also important, while in Europe, environmental goals are frequently cited in support of CAV projects. In Asia, high-tech themes generate enthusiasm from communities that want to be the first to embrace future technologies.

GENERATING EXPERTISE

Working on CAV projects has been a boon to several private companies, research institutions, countries, states, and transportation management agencies. Companies in Taiwan and Australia have developed technology that has been involved CAV projects across the world. Michigan companies wishing to play a role in CAV technologies will need to keep this global lesson in mind and could stand to benefit from capturing larger markets if they take leadership roles and foster international partnerships.

Developing expertise as a way to create future opportunities is also applicable to national and state agencies. For example, early work in Sweden built up competence and led to many follow-on projects. Within the United States, leading states have used past successes to demonstrate their ability to carry out work in competitive bids for federal projects.

REGULATING TECHNOLOGY TO MAKE A STRONG BUSINESS CASE

Successful deployment of CAV technologies requires a strong business case. For some application areas, such as infotainment, internet, and navigation, commercial entities likely will deploy them in response to consumer demand. Due to the costs of deployment, technological constraints, and the number of equipped vehicles required for safety applications, leadership from national and state governments is crucial to the deployment of connected vehicle safety technology. Regulation has an important role in encouraging technology deployment—without USDOT activities developing and testing DSRC, it is unlikely that automakers would have announced plans to bring equipped vehicle to market in the near future.

Regulation also plays an important role in the adoption of automated features in vehicles. Already, NHTSA has regulated several automated vehicle technologies and is considering regulation of additional safety systems. In addition, several US states have taken steps toward regulating the use of fully automated vehicles on public roads in order to facilitate testing activities from private firms. National level regulations may be required to ensure the safety and facilitate mainstream adoption of fully automated vehicles in coming years. For now, though NHTSA has only issued guidelines for states considering regulations to permit fully automated vehicles on public roads.[117]

CREATING GLOBAL STANDARDS

Global standards and architectures for CAV technologies would strengthen the case for private investment and deployment. By using common equipment, the production volumes can be increased, helping to bring down unit costs through economies of scale. If not at the global level, then at least at the continental level, automakers and consumers benefit from standardizing equipment and architectures so that vehicles can cross borders without losing the benefits of a CAV system and automakers can use a single system in vehicles, rather than installing different systems for vehicles being purchased in different markets.

Standardization is also seen as a competitive advantage for some countries. For instance, Japan, perceiving that German companies may have an advantage in developing standards that are consistent with their products has engaged Japanese companies in standards development.[118]

6.3 RELEVANT ISSUES FACING CAV TECHNOLOGIES

INCREASING LEVELS OF CONVERGENCE

CAV projects are more frequently utilizing both connected and automated vehicle technologies. This has been the case, for instance, with various vehicle platooning projects around the world that rely on communications and vehicle-based sensor inputs. Most automated vehicle initiatives, such as Google's self-driving car project, involve at least some form of on-board connectivity to facilitate updates.

Vehicles that use both connected and automated technologies have the potential to deliver better safety, mobility, and self-driving capability than can vehicles using either technological approach alone.[119] Adding communications technology to vehicles equipped with sensor-based systems can improve performance and enable more robust, comprehensive systems.

[117] NHTSA 2013.
[118] Young 2015.
[119] Silberg and Wallace 2012.

DECREASING DEPENDENCE ON PUBLIC INFRASTRUCTURE

As more companies are developing and testing their own CAV technologies internally or in small cooperative partnerships, there may be less demand for public agencies to provide infrastructure funding. CAV technologies that are not dependent on deployment of expansive new infrastructures can be deployed more quickly and broadly than systems that require such public investments. At the same time, the USDOT expansion of the *Connected Vehicle Pilot* project, the European investment in the *Cooperative ITS Corridor*, and the Japanese switch to ETC 2.0 all indicate a continued role for public investment in smart infrastructure.

ADDRESSING CYBERSECURITY CONCERNS

For the past year, cybersecurity has been a major issue in the news. In February 2015 BMW used over-the-air updates to fix a security flaw in its ConnectedDrive system.[120] That same month, Senator Markey of Massachusetts released a report documenting vehicle vulnerability and how automakers address cybersecurity issues. The report also discussed the collection, use, and protection of data. The report concluded that new standards are needed to adequately protect vehicles.[121] CAR held a briefing automotive cybersecurity shortly after the release of the Markey report,[122] and in the July 2015, Wired Magazine reported on hackers who were able remotely controlled some vehicle systems of a Jeep Cherokee.[123]

Responding to looming cybersecurity issues, automakers have partnered together to create an Information Sharing and Analysis Center (ISAC) to share information about vulnerabilities and attacks. The ISAC is expected to begin operations by the end of 2015.[124] As vehicles include more CAV technologies, strong cybersecurity measures and policies will become ever more important for all involved stakeholders.

COMPETING REGIONALLY FOR CAV TECHNOLOGY SUPREMACY

With CAV activities increasingly facilitated by private firms and less dependent on government agencies, economic developers might need to play a

[120] BBC 2015b.
[121] Markey 2015.
[122] CAR 2015.
[123] Greenberg 2015.
[124] Beene 2015.

greater role in attracting projects to specific countries (or states). Initiatives that provide a common space to develop, test, and implement CAV technologies can serve to help attract existing companies as well as support local CAV technology startups. These types of projects may even help attract larger companies interested in building their own private research centers, as the centers support potential suppliers and smaller partners, creating a cluster.[125]

While Michigan has many CAV-related assets, many companies are choosing to develop and test automated technology in other states. Although Michigan has done well attracting CAV deployments in the past, the changing environment (move towards convergence, decreased reliance on infrastructure, and cybersecurity concerns) means that Michigan cannot relax its efforts if it intends to maintain its national leadership role among public agencies in CAV development and deployment.

[125] Cregger and Dennis 2013.

REFERENCES

ABC. (2015). "First Driverless Car Trials in Southern Hemisphere to Be Held in Adelaide, Coinciding with International Conference." ABC News. July 21, 2015. (http://www.abc.net.au/news/2015-07-21/driverless-car-trials-held-in-adelaide/6636334).

ARTC. (2015). Automotive Research & Testing Center Website. Accessed August 25, 2015. (http://www.artc.org.tw/index_en.aspx).

Auto News. (2014). "Dutch Plan for Self-Driving Trucks Could Boost Introduction of Driverless Cars." Automotive News Europe. June 16, 2014. (europe.autonews.com/article/20140616/ANE/140619899/dutch-plan-for-self-driving-trucks-could-boost-introduction-of).

BBC. (2014). "UK to Allow Driverless Cars on Public Roads in January." BBC News. July 30, 2014. (http://www.bbc.com/news/technology-28551069).

BBC. (2015a). "Baidu to Launch Driverless Car Later this Year." BBC News. June 9, 2015. (http://www.bbc.com/news/technology-33062021).

BBC. (2015b). "BMW Fixes Security Flaw that Left Locks Open to Hackers." BBC News. February 2, 2015. (http://www.bbc.com/news/technology-31093065).

Barwick, Hamish. (2014). "Connected vehicle tech trial to start trucking on in NSW." Computer World. April 22, 2014. (http://www.computerworld.com.au/article/543376/connected_vehicle_tech_trial_start_trucking_nsw/).

Beene, Ryan. (2015). "Automakers Form Alliance to Bolster Cybersecurity: Industry to Open Anti-Hacking Hub." Automotive News. August 24, 2015. (http://www.autonews.com/article/20150824/OEM06/308249985/automakers-form-alliance-to-bolster-cybersecurity).

Bezzina, Debby. (2015). "Ann Arbor Connected Vehicle Test Environment." Michigan Connected Vehicle Working Group Presentation. January 21, 2015. (http://www.michigan.gov/documents/mdot/Michigan_CV_Working_Group_January_21st_2015_480904_7.pdf).

BMVBS. (2013). "Cooperative ITS Corridor: Joint Deployment." Federal Ministry of Transport, Building, and Urban Development, Germany. June 2013. (http://www.bmvbs.de/cae/servlet/contentblob/112732/publicationFile/78007/cooperative-its-corridor.pdf).

Boudette, Neal E. (2015). "Apple Eyes Proving Grounds for Self-Driving Car, Report Says." Automotive News. August 14, 2015.

(http://www.autonews.com/article/20150814/OEM06/150819906/apple-eyes-proving-grounds-for-self-driving-car-report-says).

Bradley, Grant. (2015). "Uncertain Territory for Driverless Cars." New Zealand Herald. May 30, 2015. (http://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=11456992).

Bristol. (2014). "VENTURER consortium to test driverless cars in Bristol region." Bristol City Council. December 3, 2014. (http://www.bristol.gov.uk/press/venturer-consortium-test-driverless-cars-bristol-region).

CAR. (2015). "Connected and Automated Vehicles and the Cybersecurity Threat: How Industry is Responding." CAR Breakfast Briefing Series. February 17, 2015. (http://www.cargroup.org/?module=Page&sID=2015-february-cybersecurity-breakfast-briefing).

Castle, Colin. (2015). "Michigan DOT Connected Vehicles." Michigan Traffic Safety Summit 2015 Presentation. March 24, 2015. (http://www.michigan.gov/documents/msp/Connected_Vehicles__Autonomous_trucks_-Castle_485666_7.pdf).

Cherry, Gabe. (2015). "U-M will test 3D-printed, autonomous SmartCarts." University of Michigan. July 9, 2015. (http://ns.umich.edu/new/releases/23006-u-m-will-test-3d-printed-autonomous-smartcarts).

CMU. (2015a). "Uber, Carnegie Mellon Announce Strategic Partnership and Creation of Advanced Technologies Center in Pittsburgh." Carnegie Mellon University. February 2, 2015. (http://www.cmu.edu/news/stories/archives/2015/february/uber-partnership.html).

CMU. (2015b). "General Motors-Carnegie Mellon Autonomous Driving Collaborative Research Lab." Carnegie Mellon University. Accessed August 17, 2015. (http://varma.ece.cmu.edu/GM-CMU-AD-CRL/index.shtml).

CMU. (2015c). "Technologies for Safe and Efficient Transportation: A USDOT University Transportation Center." Carnegie Mellon University. Accessed August 17, 2015. (http://utc.ices.cmu.edu/utc/index.html).

Compass4D. (2015). Cooperative Mobility Pilot on Safety and Sustainability Services for Deployment Website. Accessed August 26, 2015. <http://www.compass4d.eu/>.

Cooperative ITS Corridor. (2015). Cooperative ITS Corridor Website. Accessed August 19, 2015. (http://c-its-korridor.de/).

Cregger, Joshua. (2014). "International Survey of Best Practices in Connected and Automated Vehicle Technologies: 2014 Update." Center for Automotive Research. Report Prepared for Michigan Department of Transportation. September 26, 2014. (http://www.michigan.gov/mdot/0,1607,7-151-9621_11041_38217---,00.html).

Cregger, Joshua and Eric Paul Dennis. (2013). "Automated and Connected Vehicle Technologies: The Automotive Industry's New Frontier." 2013 Automotive/Aerospace Site Guide. Area Development. Summer 2013. Pages 26-30. (http://www.areadevelopment.com/Automotive/2013-Auto-Aero-Site-Guide/regions-leading-connected-vehicle-tech-investment-2822210.shtml).

CTV. (2015). "Dutch Approve Driverless Cars for Public, Large-scale Testing." CTV News. January 24, 2015. (www.ctvnews.ca/sci-tech/dutch-approve-driverless-cars-for-public-large-scale-testing-1.2203969).

Davies, Chris. (2015). "Virginia Opens Roads to Self-driving Cars" Slash Gear. June 1, 2015. (http://www.slashgear.com/virginia-opens-roads-to-self-driving-cars-01386129/).

Denso. (2014). "Denso Tests Advanced Driving Support Technology on a Public Road in Japan." Denso Global. July 14, 2014. (http://www.globaldenso.com/en/newsreleases/140714-01.html).

DITCM. (2015) "Netherlands Opens Its Doors to Driverless Cars Testing." DITCM Innovations. January 26, 2015. (www.ditcm.eu/news/343-netherlands-opens-its-doors-to-driverless-cars-testing).

DW. (2015). "Alibaba to Invest in Smart Cars, Snapchat." Deutsche Welle. March 12, 2015. (http://www.dw.com/en/alibaba-to-invest-in-smart-cars-snapchat/a-18309663).

Emirates 24/7. (2015). "Driving Dubai on the Fast-Track to Being Super-Connected." Emirates 24/7. October 31, 2015. (http://www.emirates247.com/news/emirates/driving-dubai-on-the-fast-track-to-being-super-connected-2015-10-31-1.608760).

Emma-Iwuoha, Lisa. (2015). "Driverless Cars in South Africa." Michalsons. April 24, 2015. (http://www.michalsons.co.za/driverless-cars-south-africa/15449).

ERTICO. (2015). "FOT-Net Data." ERTICO-ITS Europe. Accessed August 17, 2015. (ertico.com/projects/fot-net-data/).

FABRIC. (2015). Feasibility Analysis and Development of On-Road Charging Solutions for Future Electric Vehicles Website. Accessed August 17, 2015. (www.fabric-project.eu).

Fitch, Kent. (2015). "Canberra Autonomous Car Simulation." Project Computing. Accessed August 14, 2015. (http://www.projectcomputing.com/resources/cacs/).

FOT-Net. (2015). FOT-Net Wiki. Accessed August 17, 2015. (http://wiki.fot-net.eu/index.php/Welcome_to_the_wiki_of_Field_Operational_Tests).

Gibbs, Samuel. (2015). "China's Baidu could beat Google to self-driving car with BMW." The Guardian. June 10, 2015. (http://www.theguardian.com/technology/2015/jun/10/baidu-could-beat-google-self-driving-car-bmw).

GoMyWay. (2015). GoMyWay Website. Accessed August 25, 2015. (http://gomyway.com/).

Google. (2015). "Google Self-Driving Car Project Monthly Report: May 2015." Google. June 3, 2015. (http://static.googleusercontent.com/media/www.google.com/en/us/selfdrivingcar/files/reports/report-0515.pdf).

Greenberg, Andy. (2015). "Hackers Remotely Kill a Jeep on the Highway—with Me in It." Wired Magazine. July 21, 2015. (http://www.wired.com/2015/07/hackers-remotely-kill-jeep-highway/).

Habibovic, Azra. (2014). "R&D in Vehicle Automation: Results from the ARV-Project." Strategic Vehicle Research and Innovation - Vision, Trends and International Outlook! ICFTU Program Conference. November 6, 2014. (http://www.vinnova.se/PageFiles/751325020/Azra%20Habibovic_%20Automated%20driving_FFI.pdf).

Harman, Alan. (2015). "Australia Gearing for Autonomous-Vehicle Trials." WardsAuto. July 27, 2015. (http://wardsauto.com/vehicles-technology/australia-gearing-autonomous-vehicle-trials).

ITRI. (2015). Industrial Technology Research Institute Website. August 25, 2015. (https://www.itri.org.tw/eng/).

ITS-JPO. (2015). "CV Pilot Deployment Program." ITS-JPO, U.S. Department of Transportation. September 14, 2015. (http://www.its.dot.gov/pilots/).

ITS Germany. (2015). "German Best Practice Projects in Relation to the European ITS Action Plan." ITS Germany. March 2015. (http://docbox.etsi.org/Workshop/2015/201503_ITSWORKSHOP/SESSION02_CITS_Release1andUsageofStandards/ITSDEUTSCHLAND_EVERS.pdf).

ITS International. (2013). "Israel Aspires to ITS-led Future." ITS International. June 2013. (http://www.itsinternational.com/sections/comment-interview/interviews/israel-aspires-to-its-led-future/).

ITS International. (2015a). "Scania Tests Truck Platooning." ITS International. February 11, 2015. (www.itsinternational.com/categories/location-based-systems/news/scania-tests-truck-platooning/).

ITS International. (2015b). "First Trial of Driverless Vehicles, Regulatory Review Launched." ITS International. February 11, 2015. (http://www.itsinternational.com/categories/utc/news/first-trial-of-driverless-vehicles-regulatory-review-launched/).

ITS South Africa. (2015). ITS South Africa Website. Accessed August 25, 2015. (http://www.itssa.org/).

Jaguar Land Rover. (2015). "Jaguar Land Rover Announces Technology Research Project To Detect, Predict And Share Data On Potholes." Jaguar Land Rover. June 10, 2015. (http://newsroom.jaguarlandrover.com/en-in/jlr-corp/news/2015/06/jlr_pothole_alert_research_100615/).

Jupiter. (2015). Joint European Project for International ITS/EGNSS Awareness Raising Website. Accessed August 19, 2015. (http://jupiter-egnss-its.eu/).

Kable. (2014). "European Test Drive of 'Communicating Cars' Technology Complete." Road Traffic Technology, Kable Intelligence Limited. November 21, 2014. (http://www.roadtraffic-technology.com/news/newseuropean-test-drive-of-communicating-cars-technology-completed-4446970).

Kosoff, Maya. (2015). "Pizza Hut Is Experimenting with Connected Cars So You Can Order Food While You Drive, Without Your Phone." Business Insider. March 2, 2015. (http://www.businessinsider.com/visa-and-pizza-hut-show-connected-cars-experiment-2015-3).

Kubota, Yoko. (2015). "Toyota Creates Department to Unify 'Connected Car' Technologies." Wall Street Journal. March 6, 2015. (http://blogs.wsj.com/corporate-intelligence/2015/03/06/toyota-creates-department-to-unify-connected-car-technologies/).

Kurylko, Diana. (2015). "Volvo Self-Driving Car to Hit Swedish Roads." Automotive News. March 1, 2015. (http://www.autonews.com/article/20150301/OEM06/303029948/volvo-self-driving-car-to-hit-swedish-roads).

Lazzaro, Sage. (2015). "Self-Driving Cars Will Be in 30 US Cities by the End of Next Year." Observer. March 5, 2015. (http://observer.com/2015/03/self-driving-cars-will-be-in-30-u-s-cities-by-the-end-of-next-year/).

Lee, Terence. (2014). "Singapore's Self-Driving Car Makes Google's Version an Unnecessary Luxury." Tech in Asia. January 30, 2014. (http://www.techinasia.com/singapores-selfdriving-car-googles-version-unnecessary-luxury/).

LTA. (2015). "Joint News Release by the Land Transport Authority & JTC - Look, Hands Free! Driverless Vehicles to Ply Roads in One-North." Singapore Land Transport Authority. January 13, 2015. (http://www.lta.gov.sg/apps/news/page.aspx?c=2&id=453eb7c1-bb81-4243-a77a-d30d2c811b9b).

Main, Douglas. (2013). "Autonomous Cars Patrol Israeli Border." Tech News Daily. March 15, 2013. (http://www.technewsdaily.com/17350-self-driving-cars-israel.html).

Manibo, Medilyn. (2014). “Driverless Electric Car Launched in Singapore.” Eco-Business. January 29, 2014. (http://www.eco-business.com/news/driver-electric-car-launched-in-singapore/).

Markey, Edward J. (2015). “Tracking & Hacking: Security & Privacy Gaps Put American Drivers at Risk.” US Senate. February 2015. (http://www.markey.senate.gov/imo/media/doc/2015-02-06_MarkeyReport-Tracking_Hacking_CarSecurity%202.pdf).

Martinez, Michael. (2015). “‘Smart’ Freeway Rises on I-96, I-696.” The Detroit News. August 24, 2015. (http://www.detroitnews.com/story/business/autos/2015/08/23/sensors-detroit-expressways--talk-cars/32237821/).

Masarak. (2015). Masarak Website. Accessed August 21, 2015. (http://www.masarak.com/).

MDOT. (2014). “MDOT Partners with GM, Ford, and the University of Michigan on Country's Largest Deployment of Connected Vehicle and Highway Technologies.” Michigan Department of Transportation. September 7, 2014. (http://www.michigan.gov/mdot/0,4616,7-151-9620_11057-336809--,00.html).

MENA Herald. (2015). “Nissan Teams up with Etisalat to Develop the UAE’s Connected Car Ecosystem; Launches Region’s First Nissan ‘Smartcar’ Application.” MENA Herald. November 10, 2015. (https://menaherald.com/en/2015/11/10/nissan-teams-up-with-etisalat-to-develop-the-uaes-connected-car-ecosystem-launches-regions-first-nissan-smartcar-application/).

Moon, Mariella. (2015). “Uber's Experimental Cars Are Driving Around Pittsburgh.” Engadget. May 22, 2015. (http://www.engadget.com/2015/05/22/uber-test-car-pittsburgh/).

Morelli, Brian. (2015). “Eastern Iowa Considered for Autonomous-Vehicle-Only Roadway.” The Gazette. May 29, 2015. (http://thegazette.com/subject/news/eastern-iowa-considered-for-autonomous-vehicle-only-roadway-20150529).

Mozée, Carla. (2014). “No Steering Wheel, No Problem: Driverless Cars Set to Hit U.K. Roads.” Market Watch, the Wall Street Journal. July 30, 2014. (http://blogs.marketwatch.com/themargin/2014/07/30/no-steering-wheel-no-problem-driverless-cars-set-to-hit-u-k-roads/).

MTC. (2015). Mobility Transformation Center Website. University of Michigan. August 5, 2015. (http://www.mtc.umich.edu/).

Nelson, Gabe. (2015). “Google in Talks with OEMs, Suppliers to Build Self-Driving Cars.” Automotive News. January 14, 2015. (http://www.autonews.com/article/20150114/OEM09/150119815/google-in-talks-with-oems-suppliers-to-build-self-driving-cars).

Newcomb, Doug. (2014). "Taking Volvo's Self-Driving Car for a Spin." PC Magazine. May 15, 2014. (http://www.pcmag.com/article2/0,2817,2458072,00.asp).

NHTSA. (2013). "Preliminary Statement of Policy Concerning Automated Vehicles." National Highway Traffic Safety Administration, US Department of Transportation. May 30, 2013. (http://www.nhtsa.gov/staticfiles/rulemaking/pdf/Automated_Vehicles_Policy.pdf).

NHTSA. (2014). "US Department of Transportation Announces Decision to Move Forward with Vehicle-to-Vehicle Communication Technology for Light Vehicles." National Highway Traffic Safety Administration, US Department of Transportation. February 3, 2014. (http://www.nhtsa.gov/About+NHTSA/Press+Releases/2014/USDOT+to+Move+Forward+with+Vehicle-to-Vehicle+Communication+Technology+for+Light+Vehicles).

NSW. (2015). "Cooperative Intelligent Transport Initiative." Transport for New South Wales. December 1, 2015. (http://roadsafety.transport.nsw.gov.au/research/roadsafetytechnology/cits/citi/index.html).

NTU. (2015). "The NTU-ME Autonomous Vehicle Team Successfully Demonstrated an Autonomous EV Fleet at 2015 SAE Automated Vehicle Demonstration Competition." National Taiwan University. July 17, 2015. (http://www.ntu.edu.tw/english/spotlight/2015/569_20150717.html).

Oliveira, Marcos. (2013). "Driverless Car: Brazilian Projects Involving Autonomous Vehicles Are Contributing to the Future of Urban Mobility." Pesquisa FAPESP. November 2013. (http://revistapesquisa.fapesp.br/en/2014/01/31/driverless-car/).

OPTICITIES. (2015). OPTICITIES Website. Accessed August 19, 2015. (http://www.opticities.com/).

QMIC. (2015). "Connected Vehicles." Qatar Mobility Innovations Center Website. Accessed August 21, 2015. (http://www.qmic.com/solutions/connected-vehicles/).

Ramsey, Mike and Douglas MacMillan. (2015). "Carnegie Mellon Reels After Uber Lures Away Researchers." Wall Street Journal. May 31, 2015. (http://www.wsj.com/articles/is-uber-a-friend-or-foe-of-carnegie-mellon-in-robotics-1433084582).

Ross, Philip E. (2015). "For China's Alibaba, the Magic Word Is 'Connected Car.'" IEEE Spectrum. March 13, 2015. (http://spectrum.ieee.org/cars-that-think/transportation/self-driving/for-chinas-alibaba-the-magic-word-is-connected-car).

Schofield, Charlotte. (2014). "'UK Autodrive' Consortium Wins Competition to Develop Driverless Cars." Arup. December 3, 2014. (http://www.arup.com/News/2014_12_December/02_Dec_Consortium_wins_competition_to_develop_driverless_cars.aspx).

Scott, Mark. (2015). “Britain Offers Itself as a Proving Ground.” New York Times. June 10, 2015. (http://bits.blogs.nytimes.com/2015/06/10/britain-offers-itself-as-a-proving-ground/?_r=2).

Shimoyama, Yuji and Ippei Minetoshi. (2015). “Smart Motorists Rewarded with 'Smart' New Toll Collection Device.” The Asahi Shimbun. August 1, 2015. (http://ajw.asahi.com/article/business/AJ201508010042).

Silberg, Gary and Richard Wallace. (2012). “Self-Driving Car: The Next Revolution.” KPMG and Center for Automotive Research. August 6, 2012. (http://www.cargroup.org/?module=News&event=View&newsID=30).

Simpson, Burney. (2015a). “VA Tech Leaves ‘Em Eating Its Dust in the Race to be the Top Driverless Test Track.” Driverless Transportation. Accessed June 2015. (http://www.driverlesstransportation.com/va-tech-leaves-em-eating-its-dust-in-the-race-to-be-the-top-driverless-test-track-10061).

Simpson, Burney. (2015b). “No Slowing Down Google in Driverless Cars.” Driverless Transportation. July 11, 2015. (www.driverlesstransportation.com/no-slowing-down-google-in-driverless-cars-10383).

SMART. (2014). “SMART Launches First Singapore-Developed Driverless Car Designed for Operations on Public Roads.” Singapore-MIT Alliance for Research and Technology. January 28, 2014. (http://smart.mit.edu/news-a-events/press-room/article/42-smart-launches-first-singapore-developed-driverless-car-designed-for-operations-on-public-roads-.html).

Smith, Matt. (2015). “Update on Michigan Smart Corridor.” Michigan Connected Vehicle Working Group Presentation. May 5, 2015.

Southampton. (2015). “University to Contribute to £11 Million Driverless Cars Project.” University of Southampton. October 9, 2015. (http://www.southampton.ac.uk/news/2015/10/driverless-cars-epsrc-funding.page).

Swidey, Neil. (2015). “Where’s My Self-driving Car?” Boston Globe. June 3, 2015. (https://www.bostonglobe.com/magazine/2015/06/03/where-driverless-car/QQgIeX120N73tj3DH67JyM/story.html).

TRB. (2015). “Review of the USDOT Report on Connected Vehicle Initiative Communications Systems Deployment.” Transportation Research Board. April 27, 2015. (http://www.trb.org/Main/Blurbs/172448.aspx).

TS Catapult. (2015). “Transport Systems Catapult Unveils UK's First Driverless Pod.” Transport Systems Catapult. February 11, 2015. (https://ts.catapult.org.uk/-/transport-systems-catapult-to-unveil-uk-s-first-driverless-pod).

Urmson, Chris. (2014). “Just Press Go: Designing a Self-driving Vehicle.” Google Official Blog. May 27, 2014. (http://googleblog.blogspot.com/2014/05/just-press-go-designing-self-driving.html).

USDOT. (2015). “CV Pilots Deployment Project.” Intelligent Transportation Systems Joint Program Office, US Department of Transportation. Accessed August 19, 2015. (http://www.its.dot.gov/pilots/).

Vlasic, Bill. (2015). “Among the States, Self-Driving Cars Have Ignited a Gold Rush.” New York Times. August 6, 2015. (http://www.nytimes.com/2015/08/07/automobiles/self-driving-cars-ignite-gold-rush-among-states.html?_r=0).

Volvo Trucks. (2015). “Proving ground – how Volvo Trucks shape the vehicle safety of the future” Volvo Trucks Magazine. February 19, 2015. (http://mag.volvotrucks.com/global/global/article/?art=4084&ref=1#sthash.1rsNkCAZ.dpuf).

Volvo. (2014a). “Volvo Car Group’s First Self-driving Autopilot Cars Test on Public Roads around Gothenburg.” Volvo Car UK Ltd. Press Release. April 29, 2014. (www.media.volvocars.com/global/en-gb/media/pressreleases/145619/volvo-car-groups-first-self-driving-autopilot-cars-test-on-public-roads-around-gothenburg).

Volvo. (2014b). “Volvo Cars Approaches Crash-free Future with Opening of AstaZero Proving Ground.” Volvo Car Group Global Newsroom. August 21, 2014. (https://www.media.volvocars.com/global/en-gb/media/pressreleases/149506/volvo-cars-approaches-crash-free-future-with-opening-of-astazero-proving-ground?utm_campaign=NewsAlert_4562&utm_medium=Email&utm_source=media.volvocars.com).

VRA. (2015). Vehicle and Road Automation Website. Accessed August 19, 2015. (http://vra-net.eu/).

Wakefield, Jane. (2015). “Driverless Car Review Launched by UK Government.” BBC News. February 10, 2015. (http://www.bbc.com/news/technology-31364441).

Wallace, Richard and Valerie Sathe Brugeman. (2008). “National Survey of Best Practices in Vehicle Infrastructure Integration.” Center for automotive Research. Report Prepared for Michigan Department of Transportation. June 30, 2008.

Wallace, Richard and Valerie Sathe Brugeman. (2009). “Michigan Department of Transportation VII Test Bed Inventory Report.” Center for automotive Research. Report Prepared for Michigan Department of Transportation. April 22, 2009.

Wallace, Richard, Valerie Sathe Brugeman, and Joshua Cregger. (2012). “International Survey of Best Practices in Connected Vehicle Technologies: 2012 Update.” Center for Automotive Research. Report Prepared for Michigan Department of Transportation. September 2012.

Wallace, Richard, Valerie Sathe Brugeman, and Joshua Cregger. (2013). "International Survey of Best Practices in Connected and Automated Vehicle Technologies: 2013 Update." Center for Automotive Research. Report Prepared for Michigan Department of Transportation. August 2013.

Wallace, Richard, Valerie Sathe Brugeman, Joshua Cregger, and Michael Forster. (2011). "International Survey of Best Practices in Connected Vehicle Technologies." Center for Automotive Research. Report Prepared for Michigan Department of Transportation. August 25, 2011.

Walsh, Dustin. (2015). "Google Puts Its Self-Driving Car in the Hands of Area Suppliers." Crain's Detroit Business. January 18, 2015. (http://www.crainsdetroit.com/article/20150118/NEWS/301189977/google-puts-its-self-driving-car-in-the-hands-of-area-suppliers).

Whitelegg, J. and G. Haq. (2006). "Vision Zero: Adopting a Target of Zero for Road Traffic Fatalities and Serious Injuries." Stockholm Environmental Institute. 2006. (http://sei-international.org/mediamanager/documents/Publications/Future/vision_zero_FinalReportMarch06.pdf).

Wilton, Pete. (2015). "8 Things about Oxford's Driverless Tec." University of Oxford. February 11, 2015. (http://www.ox.ac.uk/news/science-blog/8-things-about-oxford%E2%80%99s-driverless-tech).

Yamamoto, Takumi (2014). "Updates on Japan's ITS." Presentation. 21st World Congress on Intelligent Transport Systems, Cobo Center, Detroit. September 7, 2014. (http://stsmo.transportation.org/Documents/2%20-%20Takumi%20YAMAMOTO%20Pdf.pdf).

Young, Angelo. (2015). "Self-Driving Cars: Japan Wants To Establish Global Standard For Autonomous Vehicle Technology, Safety, Infrastructure." International Business Times. February 26, 2015. (http://www.ibtimes.com/self-driving-cars-japan-wants-establish-global-standard-autonomous-vehicle-technology-1829404).

APPENDIX A: LIST OF ABBREVIATIONS

Abbreviation	**Meaning**
3G/4G	Third/fourth generation mobile telecommunications technology
A*STAR	Agency for Science, Technology and Research
AACVTE	Ann Arbor Connected Vehicle Testing Environment
ADAPTIVE	Automated Driving Applications & Technologies for Intelligent Vehicles
AD-CRL	GM-Carnegie Mellon Autonomous Driving Collaborative Research Lab
ARTC	Automotive Research and Testing Center
ASV	Advanced Safety Vehicle
CAR	Center for Automotive Research
CAV	Connected and automated vehicle
CMU	Carnegie Mellon University
Compass4D	Cooperative Mobility Pilot on Safety and Sustainability Services for Deployment
DARPA	Defense Advanced Research Projects Agency
DSRC	Dedicated Short Range Communications
DSSS	Driving Safety Support Systems
EGNSS	European Global Navigation Satellite Systems
ERTICO	European Road Transport Telematics Implementation Co-Ordination Organization
ETC	Electronic toll collection
EUCAR	European Council for Automotive R&D
FABRIC	Feasibility Analysis and Development of On-Road Charging Solutions for Future Electric Vehicles
FOT	Field Operational Test

Abbreviation	Meaning
GATEway	Greenwich Automated Transport Environment
GHz	Gigahertz
GM	General Motors
ICAD	Iowa City Area Development Group
ICT	Information and Communications Technology
ISAC	Information Sharing and Analysis Center
ITRI	Industrial Technology Research Institute
ITS	Intelligent Transportation Systems
Jupiter	Joint European Project for International ITS/EGNSS Awareness Raising
lidar	A laser-based ranging system; the name itself is a portmanteau of "light" and "radar"
LTA	Singapore Land Transport Authority
MDOT	Michigan Department of Transportation
MIT	Massachusetts Institute of Technology
MTC	Mobility Transformation Center
NHTSA	National Highway Traffic Safety Administration
NTU	National Taiwan University
NUS	University of Singapore
radar	Originally RADAR, an acronym for "RAdio Aetection And Ranging," but the term has since become common noun, losing all capitalization
SAVI	Singapore Autonomous Vehicle Initiative
SCOT	Shared Computer Operated Transport
sim^{TD}	Safe and Intelligent Mobility Test Germany

Abbreviation	Meaning
SMART	Singapore-MIT Alliance for Research and Technology
TRB	Transportation Research Board
TSET	Technologies for Safe and Efficient Transportation
USDOT	US Department of Transportation
UTC	University Transportation Center
V2I	Vehicle-to-infrastructure
V2V	Vehicle-to-vehicle
V2X	Vehicle-to-device
VAC	Virginia Automated Corridor
VRA	Vehicle and Road Automation
VTTI	Virginia Tech Transportation Institute

APPENDIX B: CONNECTED AND AUTOMATED VEHICLE PROJECTS BY GEOGRAPHIC REGION

By Continent

Continent	Projects
Africa	2
Asia	101
Europe	189
North America	201
Oceania	14
South America	4
Grand Total	**511**

By Country

Country	Projects
Nigeria	1
South Africa	1
China	12
India	1
Israel	6
Japan	49
Qatar	2
Singapore	4
South Korea	17
Taiwan	6
Turkey	1
United Arab Emirates	3
Austria	2
Belgium	10
Finland	2
France	16
Germany	47
Greece	2
Italy	13
Netherlands	23
Norway	2
Poland	1
Portugal	1
Romania	1
Spain	7
Sweden	17
Switzerland	1
United Kingdom	16
Europe-Wide	28
Canada	6
USA	195
Australia	11
New Zealand	3
Brazil	3
Chile	1
Grand Total	**511**

By US State

State	Projects
Arizona	3
California	35
Colorado	2
District of Columbia	4
Florida	11
Georgia	1
Idaho	1
Illinois	2
Indiana	1
Iowa	1
Maryland	3
Massachusetts	2
Michigan	49
Minnesota	9
Missouri	1
Montana	10
Nevada	1
New Jersey	2
New York	8
North Carolina	2
North Dakota	1
Ohio	1
Pennsylvania	3
South Carolina	2
Texas	8
Virginia	10
Washington	1
Wyoming	1
US-Wide	20
Grand Total	**195**